# INDUSTRIAL BASE ASSESSMENT OF ALTERNATIVE FUELS FOR MILITARY USE

**Prepared by:**

**Universal Technology Corporation**
**1270 N. Fairfield Road**
**Dayton, OH 45432-2600**

**For**

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# SCOPE AND APPROACH

This study was initiated to assess the existing and emerging alternative fuels industrial base and its ability to meet evolving requirements for application in U.S. Department of Defense (DOD) and Canada Department of National Defence (DND) systems. To accomplish this, the scope included examining industrial base resources worldwide, while focusing on the specific requirement for jet fuel, which represents the largest percentage of fuel used by the military departments. In addition, this assessment looked at opportunities and barriers to the military achieving stated goals, such as the U.S. Air Force's commitment to using synthetic jet fuel in defined quantities by a certain date. A North American Technology and Industrial Base Organization (NATIBO) Alternative Fuels Working Group was formed to create an avenue for information sharing. The study leveraged information from both U.S. and Canadian sources.

To accomplish this assessment, the following approach was used:

- The military requirement for alternative fuel, and specifically jet fuel, was defined. The requirement was examined in the context of global energy demand, both current and projected, with a focus on the transportation sector, and in the context of specific requirements defined by some of the participants.
- Energy sources that can satisfy multiple requirements were examined. Emphasis was on sources other than traditional petroleum, that could provide alternative fuels, specifically jet fuel.
- The technologies associated with generation of alternative fuels were examined. Current status of the technologies capable of producing jet fuel was determined.
- Armed with detailed knowledge about requirements, energy sources, available technologies, and their application status, attention turned to assessing the drivers and determinants typically used by industry to build a business case for being in the alternative fuels business.
- Information was obtained on investments made by the U.S. and Canadian governments, with emphasis on major Department and Service sponsored research programs targeting alternative fuels technologies.
- Conclusions and findings were developed based upon the data gathered and analyzed.
- Recommendations were formulated with a focus on the best approach for DOD and DND to engage with or influence the alternative fuels industrial base.

Data in support of all these actions was obtained through extensive research and review of existing reports and documents, and contact with involved government agencies, commercial firms, industry associations, and subject matter experts.

# EXECUTIVE SUMMARY

**Background**

This study was initiated to assess the industrial base capability to support DOD and DND alternative aviation fuel initiatives. The current nature of the alternative fuel industry required looking globally to ascertain capabilities and potential trends. The study identifies significant advances in the development, refinement, and actual application of several alternative fuel generation methods in countries other than the U.S. and Canada. Further, high levels of government planning, investment, and active support is present.

**Scope and Approach**

The study focused on industrial capability for alternative fuel technology worldwide. Specific emphasis was placed on military needs, and more specifically on military aircraft requirements. Particular attention was placed on the Coal to Liquid (CTL) and Gas to Liquid (GTL) processes. The approach used included review of existing reports, analyses, and technical documents, and contact with involved government agencies, commercial firms, industry associations, and recognized subject matter experts.

It is important to understand that the entire subject area of alternative energy is complex and extremely dynamic. This report is a snapshot in time. What is true today may well not be true tomorrow. Technological maturity, economic conditions, competing political interests, and changing environmental policies/concerns directly impact current and projected alternative fuel projects. Current U.S. activity is significantly constrained by existing legislation and the uncertain nature of pending legislation.

**The Challenge/Problem –** (See Section 1)

The United States is a significant consumer of energy. For one of the dominant energy sources, petroleum, the U.S. relies heavily on imports to meet our consumption demands – approximately 60% of our crude oil is imported. Many current petroleum suppliers are located in areas of the world where political conditions could easily and rapidly lead to instability with the potential to impact the cost or availability of their products. Given that existing U.S. petroleum reserves are limited (in terms of known reserves that have been/are currently providing supply), alternative fuels from non-traditional sources warrant serious consideration. Forecasted trends reinforce these concerns as global demand for additional energy, again particularly in petroleum, continues to rise with economic development in heavily populated countries.

Canada, on a per capita basis, is also a significant energy consumer. Both the U.S. and Canada, on a per capita basis, use approximately 1.8 times the energy as other developed nations. Canada is a net exporter of both crude oil and natural gas, exporting a third of their oil production and half of the natural gas they produce to their major trading partner, the U.S. Production of both is projected to increase. Development of domestic oil sands, which contain estimated oil reserves second only to Saudi Arabia and more than eight times U.S. oil reserves, has placed Canada in a leadership position with regard to energy policy.

Environmental concerns remain a major element in exploiting new domestic sources of energy. Readily available domestic sources have been taken off the table and significant constraints

placed on all alternate fuel technologies. Environmental impact accommodation is now a key element in the decision process of any solution.

The Department of Defense (DOD) is a major consumer of energy, representing 97% of the total federal government's energy use. Within DOD, the Air Force is the major consumer of jet fuel, accounting for 64% of total DOD use. Both the DOD and the Air Force have established goals to reduce energy use and pursue alternative energy sources to reduce operating costs, reduce contribution to green house gas effects, and reduce dependence on foreign sources for energy supply.

DOD and Air Force energy use reduction and independence goals reflect a challenge to which synthetic fuels offer a solution. Overall energy strategies have been formulated to address energy needs for direct war fighting equipment (e.g., tanks, various land vehicles, aircraft, support equipment, etc.), and operations and support facilities (e.g., maintenance shops, hangars, personnel housing, etc.). Strategies focus on reduced consumption, more efficient use, and alternative fuel sources.

**Sources of Energy** – (See Section 2)

There are a variety of fossil and non-fossil sources of energy. The three major fossil fuels - petroleum, natural gas, and coal - provide the vast majority of current energy worldwide. Petroleum dominates the transportation sector, coal the generation of electricity, and natural gas the heating and the chemical industries with a growing role of as-needed gap filler in the transportation and electricity sectors.

The non-fossil category contains many interesting sources - nuclear, geothermal, hydropower, tidal power, ocean currents and temperatures, wind, solar, biomass, and hydrogen – all with important uses but, with the possible exception of biomass, no direct application to filling the aviation fuel need.

Fossil fuels as sources for alternative liquid fuels:

- Coal – can be converted to gaseous and liquid fuels. The U.S. has 27 % of the known world reserves and thus good potential for conversion to fuel. Coal however, does not present significant fuel opportunities for Canada given reserves of only approximately 1% of known world reserves. The fact that Canada obtains 62% of electricity from hydro generation, makes their coal reserves less of an issue.
- Natural gas – can be converted to liquid fuels. The U.S. has approximately 3.4% and Canada has 0.9% of the known world reserves.

Non-fossil fuels as sources for alternative liquid fuels:

- Bio-mass – provides extensive multiple sources, ranging from foods to waste organic materials, it can be used in several ways to produce energy, to include liquid fuels.

Petroleum, in addition to its traditional liquid form, can be obtained from "alternative sources". The significant domestic quantities available strongly suggest that they be considered.

- Petroleum – alternative sources
    - Tar sands (also called oil sands), are a combination of clay, sand, water and bitumen, a heavy black viscous oil. Tar sands can be mined and processed to extract the oil-rich bitumen, which is then refined into oil. The U.S. has an

estimated 12 to 16 billion barrels of tar sands oil reserves in Eastern Utah. Canada's development of the extensive oil sands deposits in Alberta has provided a significant domestic supply and export opportunity. Government-industry partnerships laid the foundation for a decade of technology breakthroughs and environmental improvements in the Canadian oil sands. This partnership provides an example of how working together to overcome the challenge of establishing alternative petroleum sources can contribute to economic growth and energy security.

  - Oil shale, which refers to any sedimentary rock that contains materials called kerogen, is another source. Oil shale must be heated in order to extract the oil. The U.S. government estimates a total of 1.8 trillion barrels of shale oil exist in the Colorado, Utah and Wyoming region.

**Alternative Fuel Technologies** – (See Section 3 and Appendix A)

It is necessary to understand the level of technological maturity of the processes that can generate liquid fuels from the available energy sources.

- Coal – processes for converting coal to liquid (CTL) fuels have a long, proven track record. The processes were developed in Germany and then used extensively during World War II. The primary process, the Fischer-Tropsch Process (F-T), is named after the two German scientists who discovered and developed it. The Sasol Company, in South Africa, continued development, refinement and commercial use of the process starting in the mid 1950s and continues development today. The F-T process is an indirect conversion process, which starts with synthetic gas produced from coal. The gas is then further processed into liquids and further refined. Coal can also be converted to liquid fuels using a direct liquefaction process. Again the process was developed in Germany and used extensively during World War II. The most-used process results in hydrogenation of the coal. Developed in 1913 by Fredrick Bergius and bearing his name, the process is just beginning to come back into commercial use today. Efficient, environmentally friendly implementation continues to be a challenge.

- Natural gas – can be converted to liquid fuels (GTL) using several proven processes. One is the Fischer-Tropsch process, being used by Sasol. Another, developed by Exxon-Mobil, is often referred to as the Mobil Process. Yet another player is Statoil of Norway. Shell, Exxon, and two smaller companies in the U.S., Syntroleum and Rentech, are also active players in continued development and demonstration of gas to liquid processes. All these sources claim to have viable, scalable processes. Sasol and Shell currently operate large scale commercial operations and have more under construction. Advantages in efficiency and emissions have made GTL the current synthetic fuel choice.

- Bio-mass – an energy source with direct application to generation of liquid fuels. Bio-mass can be used to generate ethanol, which can be converted to methanol, which in turn can be converted to gasoline by the proven Exxon-Mobile process. An ethanol production industry has emerged, although a marginal energy balance has made it vulnerable to low cost petroleum. Twenty percent of ethanol plants have closed during the past two year cycle of low cost petroleum. The procedure to extract and process plant oils from crops such as camelina and jatropha to produce various fuels has been demonstrated. Use of algae to generate lipids, a form of oil, has also been demonstrated.

Current cost and low yield pose challenges to being commercially viable. There are many ongoing efforts at a variety of levels in both the private and public sectors to refine bio-mass conversion processes so they can be applied economically at the commercial level. While much progress yet remains to be made, there is a direct connection to liquid fuels.

Petroleum is discussed to highlight the processes associated with the two alternative petroleum sources, oil sands and shale oil.

Petroleum alternative sources:

- Tar sands extraction processes are well established and continue to improve in commercial operations in Canada.
- Shale oil extraction is a less mature process and requires further development before it can be claimed as a viable, economical source.

**Technology Deployment –** (See Section 4)

Processes to produce to liquid fuels range from proven, mature, and commercially executed to just beyond the experimental stage. These conditions, combined with the price and availability of oil at any given time, have directly impacted the level and pace at which industry has invested in commercial applications.

- Coal
  - Coal to Liquid Indirect F-T (CTL-F-T) is an established, proven and on-going commercial industry located in South Africa. But, the first plant compatible with current regulatory requirements has yet to be built in the U.S. China is currently in the process of planning several CTL-F-T plants. While there have been several initiatives aimed at establishing this capability in the U.S., to date none has materialized. The generation of significant amounts of $CO_2$ is a major issue.
  - Coal to Liquid – Direct conversion is known as the Bergius process. This process was used in Germany during World War II, and is a proven method. While it is an established and proven process, output quality has been considered low, and it has not been in commercial use anywhere in the world until the December 2008 opening of a plant in China.
- Natural gas
  - Gas to Liquid (GTL) is an established, proven and ongoing commercial industry located mainly in South Africa. Either the indirect F-T process or a direct conversion process developed by Mobil can be used. Shell oil produces diesel from natural gas in a factory in Bintulu, Malaysia. On February 1, 2008, an Airbus A380 was the first commercial airliner to fly with GTL-based fuel. Sasol in South Africa has been increasing its use of natural gas as a feedstock for its F-T process. A major GTL plant opened in 2007 and two more are currently under construction in Qatar and Nigeria, where natural gas has previously been flared or otherwise disposed of as useless.

- Bio-mass
    - One current form of biofuel is ethanol. Ethanol production has existed for some time. In the U.S., the focus has been on corn grain feedstock, producing ethanol for use as a blending agent with existing petroleum-based fuels, or as a stand alone fuel. Ethanol presents significant energy balance and land use challenges. Strong interest led to legislative mandates being established at the federal level for pursuit of renewable bio-based fuels, particularly ethanol. Targets for production levels of biofuel projected out to the year 2022 have been established. Financial incentives have been offered to motivate producers to enter the market.
    - Aggressive efforts continue to develop other bio-mass sources, to include cellulosic materials and algae. While several successes have been claimed in the laboratory or with small scale pilots, none has reached a maturity level for large scale commercial application. Bio-mass combined with coal as feedstock to the F-T process aids in reducing the $CO_2$ footprint.
- Petroleum – alternative recovery
    - Tar sands - an established, ongoing commercial sector for recovery and production, primarily located in the province of Alberta, Canada. The current process consists of surface mining of the tar sands for further processing into crude oil. Second generation projects are currently underway using in situ recovery from underground formations. A majority of the high quality crude produced is exported to the U.S. Significant environmental issues related to water and natural gas usage and water contamination, are being addressed by emerging, new technologies.
    - Shale oil – the oil content called kerogen can be extracted from oil shale by the processing of retorting, or heating of the oil shale. Retorting can be done on the surface or using an in situ method, where in the oil shale is retorted in place by heating. Interest and investment in extracting petroleum from oil shale has risen and fallen with the price of conventional crude. Significant technical challenges and environmental issues have prevented any significant development of large scale, commercially viable facilities.

**Building the Business Case** – (See Section 5)

The viability of any alternative fuel enterprise will require a rigorous analysis of factors associated with both energy policy and energy markets. Energy policy includes four interrelated factors that can result in a changing legislative and regulatory environment:

- Political factor – government at federal and state levels is undertaking aggressive efforts to reduce greenhouse gas (GHG) emissions and develop renewable fuels. The Energy Independence and Security Act (EISA) of 2007 sets reduction goals, identifies proposed funding levels, and calls out alternative fuel production levels. It should be noted that if past history is an indicator, initiatives of this type have often failed to actually materialize, usually due to a fall in the price of crude oil. As oil prices fluctuate, governments may change incentives such as tax abatements and direct investment funding.

- Environmental factor – global warming and greenhouse gas contributions are driving establishment of legal emission levels and targets for reduction. Several of the proven alternative fuel production processes pose significant GHG emission control problems. Strategies such as the carbon cap-and-trade approach are being looked at as ways to motivate improvement and produce sources of funds. Businesses are working hard to show they are "green." Efforts are underway to continue assessing and refining carbon capture and sequestration methods.
- Life Cycle Greenhouse Gas Assessment – The concerns about climate change and emissions levels not only influence production methods, but also require their precise documentation. Life Cycle Assessment methods are used to trace the direct and indirect contributions of feed stock, land use, transportation modes, production facility construction, and fuel production processes. Results are used to compare various alternative fuels and to evaluate their comparison to traditional petroleum-based fuels.
- Economic factor – The possibility of a worldwide recession has all but shut off capital sources and led to high percentage equity requirements. Requirements to ensure that production processes can meet projected demand, and established emissions mandates are severely challenging businesses. Any solution must be a "drop in" fuel that is compatible with all the elements of the existing logistics system (e.g., transportation, distribution, and storage).
- Social factor – concerns over global warming, competition for energy, and recession are pressuring governments to act. These actions sometimes work at cross purposes when attempting to establish either incentives or barriers for alternative fuel production.

Assuming a potential supplier, despite the significant challenges, judges the policy environment as acceptable, the traditional elements of a business case must then be considered. The focus here is on the synthetic jet fuel product.

- Market analysis – in terms of government market, only the U.S. Air Force has established a goal for actual use of synthetic jet fuel. No other federal agency or department has expressed a firm intent. Commercially there are efforts underway, initial flight testing of commercial aircraft using synthetic fuels has been conducted, and a standard has been approved for F-T based synthetic fuels. However, standards have yet to be issued for other sources, such as bio-mass which would be a key factor in assuring consistent output from industry.
- Investment analysis – the choice of a synthetic fuel production process drives this element. Investment in a CTL-F-T production facility requires between three and six billion dollars and a lead time of up to ten years before production rates are reached. Increases in planned production output have a direct correlation to initial investment and start-up cycle times. There is also a limited industrial base providing equipment for these technologies. For example, extremely large reactor castings are only available at this time from overseas sources, mainly Japan. They have at least a two year lead time. A significant worldwide increase in nuclear power plant construction, which uses similar large pressure vessels, is increasing that lead time, although there is evidence of activity in the U.S. and elsewhere to develop the needed production capability. Mature process choices are CTL-F-T, GTL-F-T, or CTL Direct. In every case, up-front investment is

significant. In addition, GHG controls add additional cost and technology development challenges. Several experts, including the U.S. Department of Energy (DOE), have estimated that carbon control technologies will not be adequate to support large scale commercial operations for another decade. Issues with bio-mass continue to include costs tied to scale-up of the production processes.

- Return on Investment analysis – market demand and the price of conventional fuel will determine when (if at all) the investment will provide a return. Existing calculations are all tied to comparative costs associated with petroleum-based fuel, both for operating costs and end product cost. Analyses of various alternative fuels will typically state: "Production of this product is economically viable at XX$ per barrel of oil, and at a production rate of XX barrels per day." As the price of conventional fuel falls and ample supplies are available, the projected ROI becomes problematic.
- Risk analysis – risks include the size of the investment required, significant lead times for production facilities, the instability in the energy market, the technical challenges even when using a well established process, and the yet-to-be-proven management of GHG emissions. Consider that Sasol, which leads the world with its extensive experience and continued refinement of the CTL F-T and GTL F-T process, has experienced significant plant start-up problems with recent ventures.
- Alternatives assessment – Given the facts associated with the above elements, a business must decide if there are other places to pursue opportunities. In the case of alternative jet fuel, given the political forces, the unpredictable domestic market, the extremely high capital investment required, the length of time until a return is realized, and the risks associated with the market and technology uncertainty, it would not appear that many businesses would be motivated to enter this market.

**U.S. Regulations, Laws, and Programs –** (See Section 6)

There are several laws and federal level initiatives that, as part of their overall thrust, address alternative fuels. The primary ones and their applicable provisions are listed below.

- Clean Air Act – expanded in 1990 to include alternative fuels.
- President's Hydrogen Initiative – 2003 – hydrogen can be a key element in syngas production.
- Energy Policy Act – 2005
    - Set specific emission requirements for gasification projects.
    - Addressed carbon capture, set criteria for funding projects and provided Carbon Capture and Sequestration R&D funding at an average of $30M annually from 2006 through 2008.
- Energy Independence and Security Act (EISA) - 2007
    - Addresses Biofuels in Title II and Carbon Capture and Sequestration under Title VII.
    - Sets renewable fuel usage standards and identifies specific renewable fuels sources.

- Sets GHG reduction targets for renewable fuels.
- Provides $25M for DOE grants in support of Biofuel R&D and infrastructure.

Most recently, the U.S. House of Representatives passed the American Clean Energy and Security (ACES) Act, also known as the Waxman-Markey Act. The U.S. Senate passed the American Clean Energy Leadership Act. Both address several aspects of energy to include carbon cap-and-trade as a strategy to motivate actions to reduce GHGs.

The U.S. Department of Energy's 2009 budget in the specific area of Energy Efficiency and Renewable Energy, Biomass, and Bio-refinery Systems R&D, is $225M. Within DOE, the National Energy Technology Laboratory (NETL) supports the FutureGen Clean Coal project, which calls for construction of a first-of-its-kind coal-fueled near-zero-emissions power plant in Mattoon, Illinois. The project is a government-industry partnership. DOE's total expenditure is projected to be $1.073B. Of that, $1B is expected to come from the Recovery Act funds for carbon and storage research. The 20 member companies will contribute $20-$30M each over a four to six year period.

In DOD, the Defense Advanced Research Projects Agency (DARPA) has a Biofuels Program exploring energy alternatives and fuel efficiency in a bid to reduce the military's reliance on traditional fuel in DOD. Two commercial contractors and one university have been awarded a total of $13.1M to perform the research.

The Air Force Alternative Fuel Certification Office (AFCO), which was formed in 2007, is located at Wright-Patterson AFB. It was created to provide scientifically-based certification for synthetic fuel usage in Air Force aircraft. Efforts addressing alternative fuels were previously funded as part of the RDT&E for Aging Aircraft, but starting in 2009, the AFCO was separately funded in the amount of $28.5M for FY2009, with additional funds identified out through 2013.

**Conclusions/Recommendations**

This report's conclusions/recommendations are supported by findings from other analyses that have been conducted in the area of alternative fuels. Several of the more significant findings from those previous reports are presented here to enable full understanding of the status and potential future of the alternative fuels industrial base.

- RAND Technical Report, *Near-Term Feasibility of Alternative Jet Fuels*, was released in late 2009, after the research for this report was concluded. The joint MIT-RAND report was sponsored by the Federal Aviation Administration and draws on a 50-plus year history of research and analysis performed by MIT and RAND on alternative fuel resources for aviation and the effects of fuel on operations. The document covers background, potential fuel sources, related technologies and a look ahead. A key finding, stated in the summary is:

  *"In the next decade, up to three alternative jet fuels may be available in commercial quantities. The alternative aviation fuels that are not derived from conventional petroleum that have the greatest potential over the next decade are as follows: (1) Jet A derived from Canadian oil sands and Venezuela's VHOs; (2) FT jet fuel produced from coal, a combination of coal and biomass, or natural gas; and (3) HRJ produced by hydro processing renewable oils."*

- The *Defense Science Board Task Force on DOD Energy Strategy*, February 2008, found that DOD faces two primary energy challenges:
    - Unnecessarily high and growing battlespace fuel demand that:
        - Compromises operational capability and mission success,
        - Requires an excessive support structure at the expense of operational forces,
        - Creates more risk for support operations than is necessary, and
        - Increases life-cycle operations and support costs.
    - Almost complete dependence by military installations on a fragile and vunerable commercial power grid and national infrastructure, that places critical military and Homeland Defense missions at an unacceptably high risk of extended disruption.
    - The Task Force recommended that DOD invest in basic research to develop new fuel technologies that are too risky for private investments and to partner with private sector fuel users to leverage efforts and share burdens. The Task Force also recommended the DOD work with commercial partners to conduct full "well-to-wheel" life cycle assessments of each synthetic fuel technology under consideration.
- *Producing Liquid Fuels from Coal: Prospects and Policy Issues*; RAND ; James T. Bartis, 2008; prepared for USAF and NETL
    - *"The firms most capable of overseeing the design, construction, and operation of CTL plants are the major petrochemical companies, which have the technical capabilities and the financial and management experience necessary for investing in multibillion dollar megaprojects. They are also best suited to exploit the learning that would accompany early production experience. Yet none has announced interest in building first-of-a-kind CTL plants in the United States."*
    - *"How can the federal government encourage the early participation of these and other capable companies in the CTL enterprise? The answer lies in the creation of incentive packages that cost-effectively transfer a portion of investment risks to the federal government."*
    - *"We found that a balanced package of a price floor, an investment incentive, and an income-sharing agreement is well suited to do this. The investment incentive, such as a tax credit, is a cost-effective way to raise the private, after-tax internal rate of return in any future. A price floor provides protection in futures in which oil prices are especially low. And income-sharing agreement compensates the government for its costs and risk assumption by providing payments to the government in futures in which oil prices turn out to be high. Because the most desirable form of a balanced package depends on expectations about project costs, the government should wait to finalize its design until it has the best information on project cost that is available without actually initiating the project."*

- *"Loan guarantees can strongly encourage private investment. However, they encourage investors to pursue early CTL production experience only by shifting real default risk from private lenders to the government. …."*

- *"In summary, for the United States, our analyses indicate that the economic constraints and time required to bring carbon capture and sequestration to commercial viability will limit the maximum rate of CTL industrial development. By 2020, the maximum production level would be about 500,000 bpd. Post-2020 capability buildup could be fairly rapid, with U.S.-based CTL production in the range of three million bpd by 2030." [Rand: Producing Liquid Fuels from Coal, 2008 (47)]*

- National Academy of Sciences, *Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts, 2009.*
  - *"Attaining….reasonable quantities of alternative fuel….will require permitting and construction of ten or hundreds of conversion plants and the associated fuel transport and delivery infrastructure. It will take more than a decade for these alternative fuels to penetrate the U.S. market. In addition, investments in alternative fuels have to be protected against crude-oil price fluctuations."*
  - *"Integrated geologic $CO_2$ storage is key to producing liquid fuels from coal with greenhouse-gas life-cycle emissions comparable to those of gasoline. Commercial demonstrations of coal-to-liquid and coal-and-biomass-to-liquid fuel conversion technologies with integrated geologic $CO_2$ storage should proceed immediately if the goal is to deploy commercial plants by 2020. Detailed scenarios for market penetration of U.S. biofuels and coal-to-liquid fuels should be developed to clarify the hurdles and challenges facing full feedstock use and to establish the enduring policies required. Current government and industry programs should be evaluated to determine whether emerging biomass and coal conversion technologies can further reduce U.S. oil consumption and greenhouse-gas emissions over the next decade."*

- The MITRE Corporation, JASON Program Office, *Reducing DOD Fossil-Fuel Dependence*, 2006.
  - *"DOD is not a large enough customer to drive the fuel market or to drive future developments in alternative fuels. Accounting for less than 2% of U.S. consumption, DOD is likely to depend on the world-wide commercial sectors for its supply of alternative fuels."*
  - *"Liquid fuels from stranded natural gas provide the most economically and environmentally favorable alternatives to fuels from crude oil. Underground coal gasification (UCG) provides the next-best alternative from an economic perspective, but is only acceptable from an environmental perspective if GHG emissions (mostly$CO_2$) from the fuel production processes are sequestered."*
  - *"Presently, liquid fuel from biomass processes do not compete economically with production of fuel from crude oil. Biofuels provide little, if any, net energy benefit. This is particularly the case, if the complete process is taken into account, and it is not economically competitive (without subsidies) with other uses of agricultural land, e.g., growing food. Current biomass-to-fuel methods of*

*production present a significant environmental burden (GHG, soil depletion and erosion, waste water, etc)."*

  - *"Fuel processes based on cellulosic ethanol, butanol, etc. could eventually provide a significant fraction of the fuel demands of the U.S., if they are proven economically viable and if associated environmental burdens are acceptable. Such processes do not exist at present, however, and neither they, nor other non-ethanol biofuels and biofuel processes can be assessed, either in terms of their economics or environmental ramifications, at this time."*
  - *"Ethanol's low energy density, high flammability, and transportation difficulties, relative to diesel and JP-8, for example, render it unsuitable as a DOD fuel."*

**NATIBO Alternative Fuels Working Group Conclusions/Recommendations**

At present there is not an existing domestic industrial base or favorable business climate to support a rapid migration to use of alternative fuels sources for military aviation systems.

- Current business, environmental, economic, and social concerns present conditions that are less than favorable for a business decision to enter the alternative fuels market.
- Large project schedule slips remembered from nuclear generation plant construction and reinforced by current GTL construction experience combined with restrictive credit markets makes securing funding difficult.
- Perceived significant first article technical and integration risk is reinforced by problems experienced by the experts – Sasol Oryx, Chervon Escravos, and Shenhua Erdos.

The very pragmatic objectives that precipitated this industrial base assessment were driven by the need for source security and cost stability for required fuel. At the point the objectives were established and a process of attainment set in motion, it was assumed that a solution existed and was well on the way to commercial implementation. The technical and business community assumed that solution to be the production of synthetic fuel from coal through the Fischer-Tropsch (F-T) process.

A number of conditions have added new challenges to use of the Fischer-Tropsch process, adding technical challenges and complexity, impacting costs, and especially the anticipated implementation time-line. This situation has significantly altered future possibilities and made the recommendation of action paths significantly more complex. The following recommendation sets are based on these realities.

The recommendations below are focused on what the DOD and DND should do to actively engage with the industrial base for the purpose of enabling industry to meet the defined objective for jet fuel (both traditional and synthetic), both in terms of source and quantities. The recommendations are concentrated in four (4) focus areas that hold the greatest potential for benefit. The four focus areas are Planning, Technology Investment/Sharing, Collaboration, and Fuels Certification.

**Recommendation 1 - Planning**

DOD and DND should put plans in place that address:

- The course of action in the event of contingencies ranging from loss of supply, to a significant price increase which has catastrophic budget impact. Plans should consider various options, such as:
    - Expansion of traditional petroleum fuel sources, and equally important, additional domestic refining capacity which is currently a bottleneck. Many experts believe this would also put pressure on the global market as reduced demand has in the past two years.
    - Given current market conditions, the best role for DOD and DND is not major investment, but targeted investment in focused technologies (see technology investment/sharing below).
    - Processes involved in the application of Title 1 authorities and allocation of domestic production to national security requirements.
- Establish sustained approaches to address long term non-contingency driven energy usage and procurement, such as:
    - Continued interaction with industry (both energy producers and commercial customers) and environmental associations to maintain awareness of policy and market issues.
    - Identification and adoption of best practices in multiple areas related to energy usage, procurement, storage, and distribution.
    - Expansion of certification programs to non-aviation segments of the military enterprise.

**Recommendation 2 – Technology Investment/Sharing**

In conjunction with recommendation 1, implement a joint DOD/DND program that:

- Directly aides in and accelerates the further development, refinement, and expansion of existing small scale domestic F-T production processes, such as exist with Synthroleum and Renteck. Synthroleum was a domestic source for synthetic fuel for the initial Air Force buy in support of the Alternative Fuel Certification effort. In addition, the program should identify similar sources in Canada.
- Actively supports research to mature technologies that accelerate development of tar-sands recovery from the estimated two trillion barrel reserve located in the Green River Formation in Colorado, Wyoming, and Utah. Collaborate with Canada for technology and data sharing based on their well established tar-sands commercial experience.
    - The potentially huge quantities of fuel contained in tar sands and oil shale suggest that these sources not be summarily dismissed because of past inabilities to cope with production challenges. The NATIBO Alternative Fuels Working Group provides a direct technology/information sharing source, for the benefit of diligent, protracted problem solving.

- Evaluates the use of Title III or CRADA initiatives, and any Canadian equivalent, to demonstrate emerging processes that have operational potential as small-scale or mobile facilities.
    - Most current F-T plant designs are based on yet-to-be-validated conceptual models. The risk associated with launching a large-scale project with unproven designs and the extreme capital costs have been a major barrier to development. A necessary initial set of validation data and experience needs to be obtained at a reasonable cost and risk even if a compromise of scale efficiency is required. There are a small select number of programs that would be good candidate projects. Additionally, concepts have developed that value a small mobile fuel production capability.
    - Support an appropriate effort to achieve process maturity and scale-up, such as an advanced concept development program, a CRADA, or cost share/incentive. Incentives such as a guaranteed joint fuel quantity purchase over an extended period of time should be evaluated.

**Recommendation 3 – Collaboration**

Continued collaboration is necessary as both military requirements and the energy industry continue to rapidly change. Through formal agreements establish a government-to-government forum specifically focused on transition technologies in the area of energy processing and production. NETL could coordinate U.S. effort through an MOU between DOD and DOE. The forum would include Canadian fuels related programs under the National Research Council and associated laboratories, and U.S. DOE and DOD laboratories. Both DARPA and ARPA-E would participate. Areas of common interest should include:

- Address key areas such as carbon dioxide, water use, gasification processes, and process efficiencies. Support the demonstration of large-scale coal gasification and integrated carbon capture through the U.S DOE FutureGen and the Canadian Genesee-ASAP projects. The integration of multi-phase, continuous-flow balanced processes like coal gasification or F-T fuel production with the collection and disposition of $CO_2$ is considered a significant risk because of both the balancing challenge and the large quantities involved. Many experts have suggested that several full-scale demonstrations of this integration are a mandatory prerequisite to mature low-risk commercial implementation.
- Evaluate and document the characteristics and quality of fuel products from other coal-to-liquid fuel processes (like direct liquefaction, coal refining). The F-T process has traditionally been considered a preferred source of aviation fuel because of product quality and ease of product upgrading. However, an increasing number of developers claim that advancements in technologies have made other processes equivalent to the F-T process.
- Promote improvement of the Fischer-Tropsch process:
    - Continue F-T catalyst research.
    - Sponsor process modifications that increase efficiency and reduce water use.

    - Sponsor detailed investigation of hybrid facilities that import -rather than generate- process heat and hydrogen.
- Establish methods by which technical reports and related documents can be readily accessible to interested DOD and DND organizations.

**Recommendation 4 – Fuel Certification**

Continue fuel certification support and collaboration by DOD, DND, and a widening group of allies and international commercial airlines. Although much has been accomplished, many different emerging fuel candidates consider certification as a work in process.

A key business case element for synthetic fuel technology development and the construction of the required multi-billion dollar production facilities has always been an ensured market. Because the characteristics of aviation fuel are so tightly specified, the questions of equivalence and acceptability were significant issues. The USAF Alternative Fuel Certification effort answered these questions and defined the path forward:

- A process (MIL-HDBK-510) was established to evaluate candidate fuels and determine compatibility with aircraft engines and their fuel support systems.
- All USAF aircraft have been or are nearing certification for a 50/50 blend of FT fuels.
- Fuel, procedures, and support were provided to the Canadian DND to accomplish certification of select Canadian Forces aircraft.
- The resulting tech data formed the basis for the approval of ASTM- D7566 which set the standard for FT fuel use in commercial aircraft.
- The certification effort has now been expanded to assess and certify emerging bio-jet fuels.

Recommend the expanded use of alternative fuel certification standards and documentation such as the CAN/CGSB-3.23 (Grades Jet A and Jet A-1), CAN/CGSB-3.24 (Military Grades F-34 and F-44), U.S. MIL-DTL-83133, and MIL-DTL5624 to facilitate market growth. Once compliant to national product standards, alternative fuels could be sought and considered for procurement in support of domestic operations. For example, the established technical baseline has led thirteen commercial airlines to take initial steps toward a guaranteed purchase agreement with Rentech.

## 1.0 STATEMENT OF THE PROBLEM

### 1.1 Department of Defense Energy Objective

The energy trials and instabilities that frustrate the general population are a much more serious issue for the military establishment. Price fluxuation causes difficult budget problems, source uncertainty, unacceptable risk, and strategic vulnerability.

Michael W. Wynne was a military officer, 23 year corporate executive, four year Department of Defense executive, and the 21st Secretary of the Air Force. [1] His compelling vision for energy independence is described in excerpts from a August 11, 2008 article in Aviation Week.

> *There have been many calls for energy independence. But a political calling is not apolitical or economic result. As both the head of acquisition for the Pentagon and as Air Force Secretary, I focused on realistic and feasible ways to move forward on the concept of energy independence. There are several imperatives driving the Air Force to underwrite this development.*
>
> *First, the Air Force is the largest fuel user in the federal government, and with the volatility in fuel prices, it needed to take action to stabilize its budget. The current expenditure tops $6 billion* ($7.7 in 2008) *and with every $10 increase in a barrel of oil the impact on the Air Force is $660 million.*
>
> *Second, our international sources are becoming more precarious and some have identified with funding terror groups. Changing the leverage equation provides the U.S. with enhanced strategic flexibility. Similarly, altering the environment for defense may yield alternative diplomatic solutions by restoring price and supply stability in the uncertain area.*
>
> *The Air Force has set goals for qualifying its entire fleet and infrastructure for use of synthetic fuels by 2011 and aggressively has set a further goal to purchase 25% of its fuel from domestic synthetic sources by 2016. This would result in 50% of planned fuel use coming from a mixture of synthetic and natural JP-8.*

This objective is stated in the December 2007 *United States Air Force Energy Program* fact sheet, and many other announcements:

> *By 2016, be prepared to obtain 50% of CONUS aviation fuels from domestically produced synthetic fuel blends from domestic sources capturing and reusing $CO_2$.**

This same fact sheet states “this equates to approximately 400 million gallons of synthetic fuel” a year. There are several steps to connect these numbers:

* NOTE: the Air Force Energy Program Policy Memorandum AFPM10-1, dated Dec 19, 2008 restates this objective as: “By 2016 be prepared to cost competitively acquire 50% of the Air Force’s domestic aviation fuel requirement via an alternative fuel blend in which the alternative component is derived from domestic sources produced in a manner that is greener than fuels produced from conventional petroleum.”

- In 2006, the AF used approximately 2.6 billion gallons of aviation fuel.
- Approximately 60 % of the 2.6 billion gallons or - 1.5 billion gallons - was used in domestic operations (in the continental U.S. - CONUS).
- 50 % of that 1.5 billion gallons of CONUS fuel would be 780 million gallons.

- Given that the "synthetic fuel blend" will be composed of a 50-50 blend of synthetic fuel and traditional petroleum fuel – 390 or approximately 400 million gallons of synthetic fuel per year or 26 thousand (42 gallon) barrels per day will be required.

A bold initiative of this nature is completely consistent with the energy conservation track the Department of Defense and Air Force has been on for some time. At the end of 2007, the Air Force was the number one purchaser of renewable energy in the federal government and number three in the United States. For six consecutive years (2003-2008), the Air Force has been first on the EPA's list of top 10 federal government green power purchasers. [2] For six consecutive years (2003-2008) the Air Force has reduced the amount of aviation fuel it used. By 2011, the Air Force will have tested and certified the entire inventory of aircraft for operations with a 50/50 synthetic fuel blend. Synthetic fuel from coal and natural gas feedstock have already been certified and the program was expanded to include biofuels in early 2009.

The Department of Defense synthetic fuel and energy conservation initiatives are small elements of a much larger energy dilemma which is categorized by The Academy of Sciences and many others as a crisis. The problem of how the U.S. will meet an increasing demand for clean energy has significant technical, international relationship, and public policy aspects. The National Energy Technology Laboratory (NETL) has described the situation as the Venn diagram confluence of security, supply, and emissions control as shown in Figure 1. [3] They propose that a mixture of coal and biomass converted to liquid fuel (CBTL) is an attractive solution.

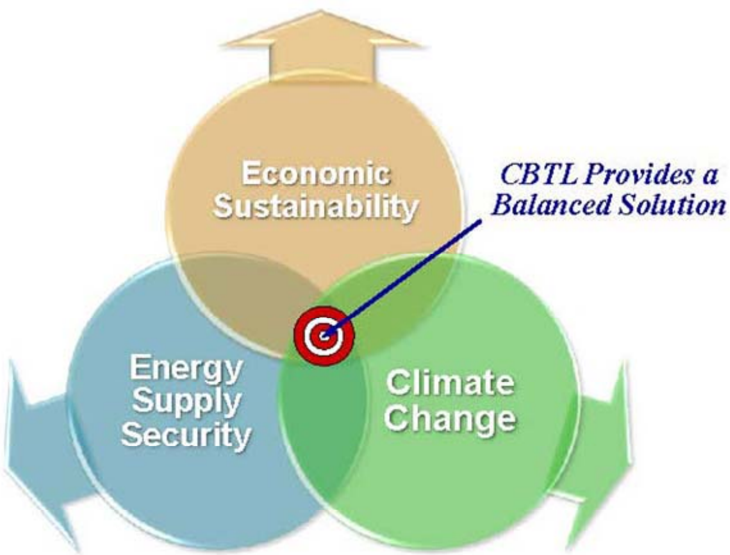


**Figure 1. Solving the Energy Strategy Dilemma**

## 1.2 Global Context

### 1.2.1 Projected Energy Demand

An expanding energy demand is predicted by many international entities to increase by more than 45% by 2030. The International Energy Agency (IEA) *World Energy Outlook 2008* [4] states:

> *"The world's energy system is at a crossroads. Current global trends in energy supply and consumption are patently unsustainable – environmentally, economically, socially. But that can – and must – be altered; there's still time to change the road we're on."*

The U.S. Department of Energy (DOE) Energy Information Administration (EIA) *Annual Energy Outlook 2009* [5] predicts growth, but at rates significantly reduced from its past *Outlooks*. The changes reflect expected emphasis on conservation, increased cost, and international competition.

> *"Total U.S. primary energy consumption (predicted in the 2009 Outlook) grows by 11.2 percent …compared to the 15.8 percent growth predicted in 2008. Among the most important factors leading to a lower total energy demand… are significantly higher energy prices and greater use of more efficient appliances and vehicles."*
>
> *"The U.S. population (is predicted to) increase by 24% from 2007 to 2030… over the same period, energy consumption increases by 11 percent. The result is a decrease in energy consumption per capita."*
>
> *"Total U.S. consumption of liquid fuels, including both fossil liquids and biofuels, (is predicted to) grow from 20.6 million barrels per day (865 million gallons per day; of which 15 million barrels per day is aviation fuel, diesel and gasoline in the transportation sector) in 2007 to 21.6 million barrels per day in 2030. Excluding growth in biofuel consumption, consumption of petroleum-based liquids is essentially flat. The transportation sector dominates demand for liquid fuels, which grows from a 69 percent share of total consumption in 2007 to a 75 percent share in 2030."*
>
> *"The moderate increase (projected) in coal consumption from 2007 to 2030 also reflects growth in coal use at coal-to-liquid (CTL) fuel plants. Despite higher CTL investment costs and concerns about potential Greenhouse Gas (GHG) regulations, the increase in coal use for CTL plants in the 2009 estimate is greater than the 2008 case because higher liquid prices increase the economic attractiveness of the technology."*
>
> *"The 2009 case includes greater (projected) use of renewable energy than the 2008 case. Total consumption of marketed renewable fuels- including wood, municipal waste, and biomass in the end-use sectors; hydroelectricity, geothermal, municipal waste, biomass, solar, and wind for generation in the electric power sector; ethanol for gasoline blending and biomass-based diesel in the transportation sector… grows by 3.3 percent per year. Although the situation is uncertain, the current state of industry and EIA's present view of the projected rates of technology development and market penetration of cellulosic biofuel technologies suggest that available quantities of cellulosic biofuels will be insufficient to meet the new (government) targets for cellulosic biofuels before 2022."*

### 1.2.2 Current Energy Use

The long existent situation where the U.S. with 5% of the world population consumes 22% of the world's energy is being challenged. Expectations in developing countries, especially China and India, are rising at unprecedented rates. In addition, increasing attention is being directed to the nearly one third of the world's population whose dismal standard of living is strongly correlated to their complete lack of electricity. India and China account for approximately half of the demand increase projected for the next twenty five years. But, even the U.S. and other developed countries are on a track that will require more capacity.

In 1980, China and India together accounted for less than 8 percent of the world's total energy consumption; in 2005 their share had grown to 18 percent. Even stronger growth is projected with their combined energy use more than doubling and their share increasing to one-quarter of

world consumption by 2030. In contrast, the U.S. share is projected to shrink to 17 percent. At the same time, the Middle East, Africa, and Central and South America are expected to see 60 percent increases. [EIA- International Energy Outlook 2008] [4]

The following two tables relate energy use to its source. When addressing fuel, the units are comfortably familiar. Unfortunately, when examining widely dissimilar sources to get a sense of share and comparison, percentage and absolute magnitude may be more helpful than terawatts or BTUs.

**Table 1. Current Total Energy Use**

| Source | World (TW) | U.S. (TW) | U.S. % of World Use |
|---|---|---|---|
| Oil | 5.6 | 1.34 | 24 |
| Natural Gas | 3.5 | .77 | 22 |
| Coal | 3.8 | .77 | 20 |
| Hydro | .9 | .09 | 10 |
| Nuclear | .9 | .27 | 30 |
| Geothermal | .13 | .01 | 8 |
| Wind, Solar, Wood | 0.0 | 0.0 | 0 |
| Total | 15.0 | 3.35 | 22 |

Energy in the United States, Wikipedia.org

Thus, for both the U.S. and world energy usage, several things stand out:

- 86% is derived from fossil fuels.
- Oil is dominant; oil, coal, and natural gas are contributors of the same order of magnitude – all other contributors are on a different scale; replacing fossil with renewable is an orders of magnitude issue.
- U.S. utilization sets the standard for all sources.

U.S. energy use and possible conservation is often tracked by end-use sector. Table 2 shows the four sectors, their share, and energy source.

**Table 2. U.S. Energy Consumption by Use Sector**

| Sector | Total Consumption | % / Total | Coal | N. Gas | Petro | Renewables |
|---|---|---|---|---|---|---|
| Residential | 21,753 | 21.4 | 9,169 | 8,860 | 1,647 | 2,077 |
| Commercial | 18,430 | 18.1 | 8,903 | 6,959 | 982 | 1,586 |
| Industrial | 32,321 | 31.8 | 8,509 | 10,903 | 9,786 | 3,123 |
| Transportation | 29,096 | 28.6 | 52 | 689 | 27,721 | 634 |
| Total | 101,600 | | 26,633 | 27,411 | 40,136 | 7,420 |

Source: EIA Tables 2.1a-e

We see:

- Coal is strong in residential, commercial, and industrial because 87% of all coal is used to supply electricity.
- Petroleum is dominant in transportation and consumes more energy in that sector than the total energy consumed in either residential or commercial.

### 1.2.3 Transportation Fuel Use

Looking at a different perspective in more common units, EIA reports that of the 20.6 million barrels (865.2 million gallons) per day of liquid fuels the U.S. consumes, 15 million barrels of it go to transportation. Figure 2 shows the historic growth of that oil use and the continuing transportation sector dominance

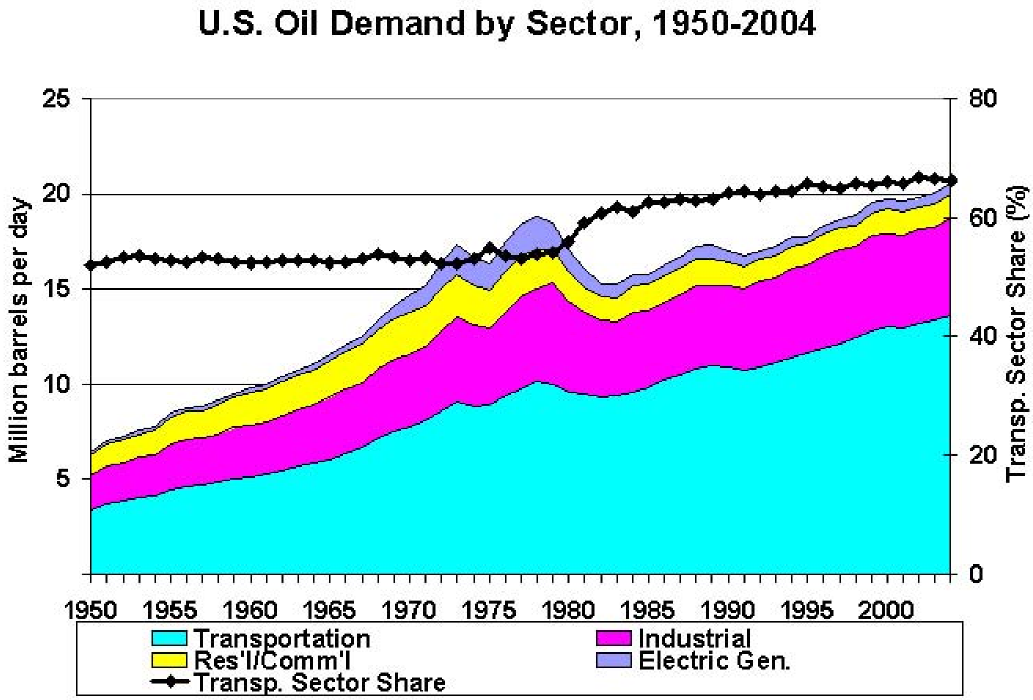


**Figure 2. U.S. Oil Demand by Sector, 1950-2004**

(EIA Annual Energy Review, Tables 5.12a & b)

Table 3 shows the 2007 transportation sector's oil use by fuel type.

**Table 3. U.S. Transportation Fuel Use**

| | Million Barrels Per Day | Million Gallons Per Day | % of Total |
|---|---|---|---|
| Gasoline | 9.2 mbpd | 386.4 mgpd | 61% |
| Diesel | 4.2 mbpd | 176.4 mgpd | 28% |
| Jet Fuel | 1.6 mbpd | 67.2 mgpd | 11% |
| Total | 15.0 mbpd | 630.0 mgpd | 100% |

EIA Table 5.13c

Note that in comparison:

| | | | | |
|---|---|---|---|---|
| USAF 2008 | 6.6 | mgpd | 1.04 | % of total |
| | | | 9.8 | % of jet fuel |
| USAF Synthetic Fuel Objective | 1.09 | mgpd | 1.6 | % of jet fuel |

There are several points to be made from these graphics.

- Oil is the dominate energy provider and all of the quantities are very large.
- Although extremely important to the Air Force, the goal of 400 million gallons per year or 1.09 million gallons per day of synthetic fuel would have been 1.6 % of the 2007 total U.S. jet fuel used or only 0.17 % of the total transportation fuel consumption.

As a result, the ability to use Air Force requirements as leverage in the market or in sponsoring a new fuel industry is not significant.

### 1.2.4 USAF Fuel Needs

The Air Force in 2006 consumed almost 2.6 billion gallons of aviation fuel at a cost of $5.7 billion, 2.5 billion gallons in 2007 at a cost of $5.6 billion and in 2008, 2.4 billion gallons at a cost of $7.7 billion dollars. Although the Air Force has consistently reduced consumption, increasing prices have significantly increased the resultant cost. [USAF Energy Program SAF/IE, Dec 2007]

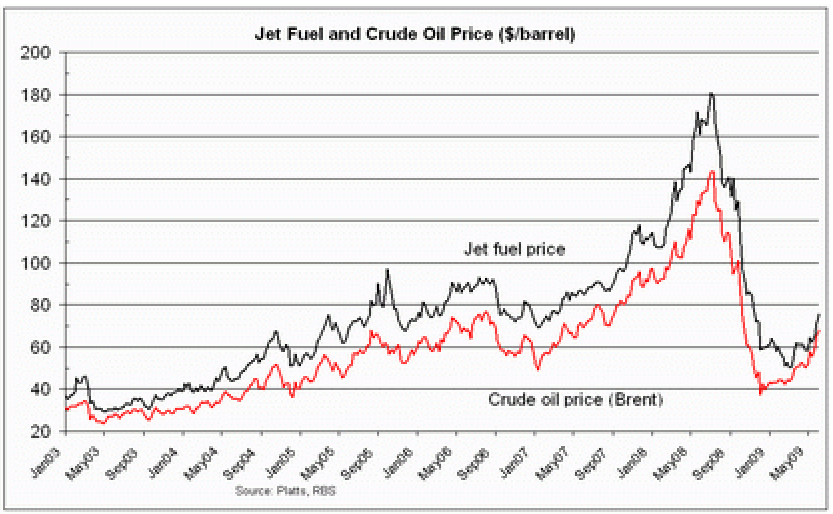


**Figure 3. Jet Fuel and Crude Oil Price ($/Barrel)**

Aviation fuel comprised 81 % of the 2008 Air Force energy budget. [6]

The DOD uses 97% of all the fuel consumed by the federal government. The Air Force is the predominate DOD aviation fuel user. In 2007, the shares were - Air Force 64%, Navy/Marines 19%, and Army 17%.

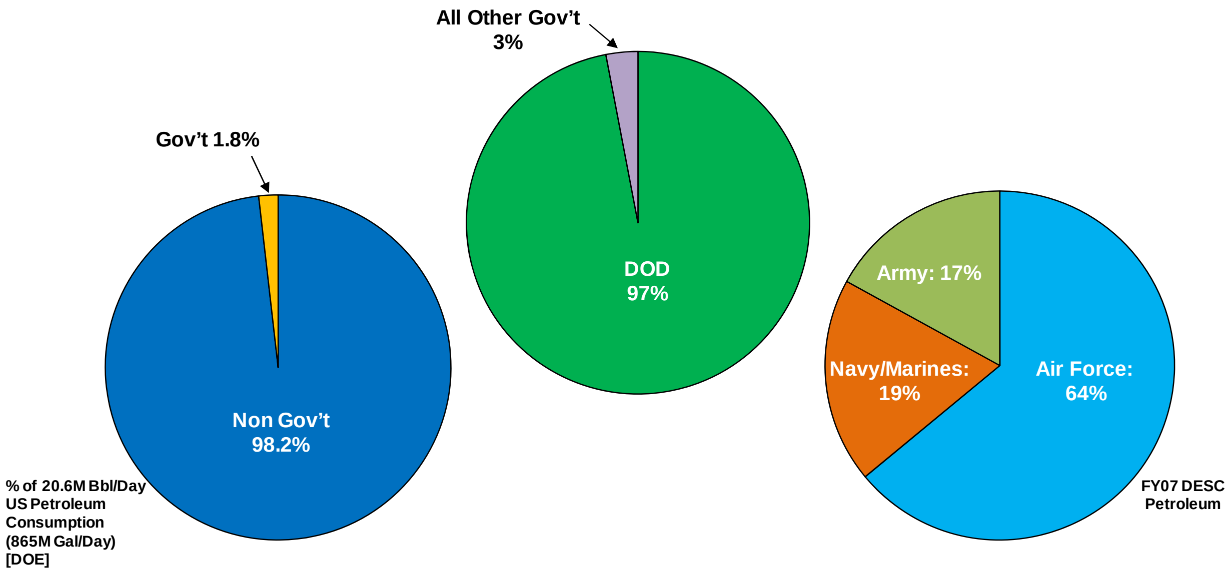


**Figure 4. U.S. Gov't, DOD AF Fuel Utilization – FY07**

DOD is the largest energy consumer in the federal government, yet used only approximately 1.8% of the energy used in the U.S. The largest single use in the DOD is jet fuel.

The future demand for Air Force fuel is the product of several varying and hard to predict factors.

The overall DOD use of aviation fuel has decreased consistently from approximately 375,000 barrels per day in 1991 to approximately 220,000 barrels per day in 2006, a 15 year decrease of approximately 40%. [7]

The national energy conservation objective is obvious in many places. The Air Force Energy Strategy dated June 2009 states the objective of reducing fuel use per hour of operation by 10% by 2015 from the 2005 baseline. [8] The Air Force total aircraft inventory as of August 2008 was 4,285, the planned procurement for the five years FY 09- FY13 is only 115 aircraft per year, [9] and the early retirement of 250 tactical fighter aircraft in FY2010 recently announced. [10] This will most probably reduce Air Force use to 2 billion gallons a year – or less- by 2016.

## 1.3 Climate Control

The international community is, despite growing need for energy use, seriously concerned about global climate policy, with particular focus on carbon dioxide. Worldwide, 30 billion metric tons of $CO_2$ are released to the atmosphere by man-made activities each year and if not addressed is projected by some organizations to increase significantly by 2030. [11]

The carbon control issue is difficult to deal with because:

- The quantities are very large.
- The man-made emissions contribution is a very small fraction of the total carbon dioxide cycle.

- The Intergovernmental Panel on Climate Change (IPCC), a United Nations organization, has expressed concerns and taken actions that are driven by a hypothesis model that does not correlate well with hard data.
- The greenhouse effect is complex, not totally reflected by the concentration of any individual atmospheric component.

James Bartis, a Senior Policy Researcher at RAND testifying before the Senate Committee on Energy and Natural Resources on March 5, 2009 pointed out that the U.S. annually releases 7 billion metric tons of $CO_2$ and almost 90% of these emissions are associated with the production and use of petroleum, coal, and natural gas, in order of decreasing contribution. Currently, over 77% of the nation's electric generating capacity is based on fossil fuels. Coal plants alone meet nearly 50% of our electricity demand and in turn contribute 82 % of $CO_2$ emissions. [12]

These quantities are huge but continue to cause extensive discussion because of their small part of the larger context. Carbon dioxide constitutes only 0.038 % of the atmosphere. Water vapor contributes 36 to 72% of the greenhouse effect while $CO_2$ adds only 9 to 26 %. [13]

Although global warming may still be open to debate, $CO_2$ concentration is not. The atmospheric $CO_2$ levels have increased from 300 ppm in 1990 to 380 ppm today and have been projected by the IPCC to double and reach dangerous levels by the end of this century. [14] Drastic curtailment measures are being called for and are achieving popular support, even in the U.S.

Significant international rebuke has been directed at the U.S. for failure to participate in the 1997 Kyoto Protocol which aimed to reduce Greenhouse Gas (GHG) emissions to 5.2% below the 1990 level (29% below the predicted 2010 levels). The protocol would have assigned a 7% reduction to the U.S. GHG emissions. The U.S., in fact, increased by 20% over the period from 1992-2007. The conference to define the next set of co-operative actions is scheduled for Copenhagen in December 2009. Some form of carbon control is judged to be inevitable. This will put huge pressure on the use of fossil fuel, raising both plant construction and production costs.

The U.S. has more energy resources in coal reserves than the Middle East has in petroleum reserves. "But, even if the conversion of coal to liquid fuel were 100% efficient, a ton of coal would yield about half a ton of fuel and two tons of carbon dioxide. The U.S. could wind up spending a great deal of money on coal liquefaction plants that would then be rendered uneconomical in light of future developments related to global warming." [15, (39)]

### 1.4 Source of Energy

The source of energy, both in type and geographic origin, is another major issue. There are still world wide oil and gas reserves to meet projected demands, but things are changing. More than 75% of the world's oil and gas reserves are now controlled by national companies [15, (9)] and thus have become a tool of political as well as economic policy. The high crude oil prices experienced in recent years have raised public awareness that not only have we experienced the greatest transfer of wealth in history, but that much of that wealth is going to finance activities that are not in the best interest of the U.S.

The desire to reduce GHG and $CO_2$ emissions in particular, promotes the reduction in use of all fossil fuels. This objective impacts oil and gas directly, but to a much greater degree puts pressure on the worst GHG offender – coal. Energy conservation and renewable energy sources

are gaining attention, but as experts point out, the magnitude of demand is so great compared to the potential yield of renewable sources that little change of source percentage can be expected in the next twenty years. The IEA World Energy Outlook 2008 reference case predicts that "fossil fuels will account for 80% of the worlds primary energy mix in 2030 – down slightly from today" unless drastic changes are made. [16]

Many of coal's functions can be – and are being replaced by natural gas, which releases only 56% of $CO_2$ released by coal for a common amount of energy. However, this short sighted action would drastically increase the cost of electricity now generated by coal, significantly impact residential and commercial heating and take natural gas from its high value use in many chemical product processes.

RAND's work on oil shale supported by the DOE National Energy Technology Laboratory (NETL) pointed out that the largest known oil shale deposits in the world are located in the Green River formation in Colorado, Utah, and Wyoming. The oil reserves in this area contain more than triple the oil reserves of Saudi Arabia. [12, (5)]

> *Energy independence should not be confused with strengthening energy security. The concept of energy independence is not realistic in the foreseeable future, whereas U.S. energy security can be enhanced by moderating demand, expanding and diversifying domestic energy supplies, and strengthening global energy trade and investment. There can be no U.S. energy security without global energy security.*" [15, (35)]

### 1.5 Energy Infrastructure

The energy infrastructure is also critical. For a variety of reasons, the U.S. is not well prepared for the energy crisis. A new refinery hasn't been built in the U.S. in 30 years. The U.S. diesel (same basic refinery output as jet fuel) demand now exceeds domestic refining capacity.

In addition to needing more electricity generating capacity to meet growing demand, we have 900 coal-fired electric generation plants that are, in effect, carbon emission non-compliant and need to be replaced. But because of greenhouse gas concerns, more than 90 new coal fired electricity generation plants have been blocked or delayed by environmentalist groups since 2002. Last year only five new coal-fired generation plants, totaling only 1,430 megawatts came on-line. [17]

No new nuclear power plants have been built in the U.S. in 30 years, so our domestic skill and component vendor base has drastically atrophied. At a time when nuclear power could be providing a carbon free source of energy, bringing it on-line is difficult.

Wind and solar sources have promise, but also present a major challenge. Neither provide a consistent feed of electricity to the grid and thus have to be balanced with other sources, usually natural gas fired generation, which raises the total cost significantly. More important, "the electrical transmission grid" is very fragile and not capable of handling source variation nor of moving large amounts of energy significant distances.

### 1.6 Energy Cost

What do all the above energy issues have to do with developing a source of synthetic jet fuel? Unfortunately, all of them are competing for the same technical and financial resources at the producer and consumer levels. For example, American families have seen household energy

cost more than double since 1997. Sixty million American households are now paying almost 25% of their total household income to cover energy-related expenditure. [11, (36)]

The extremely large reaction vessels used in similar configurations for nuclear power, coal-fired electricity generation, and Fischer-Trosch coal-to-liquid fuel production are only available from a handful of vendors in Japan, Korea and China. There is no production capability in the U.S. and lead times are currently several years. A Florida utility recently filed a nuclear power plant application, the cost of which had tripled in the last year because of material, construction, and financing costs. The handful of coal-to liquid and natural gas–to-liquid fuel production facilities now being built have all experienced significant overruns and technical problems. In today's funding environment, these manufacturing challenges and the related cost uncertainty they foster are a serious problem.

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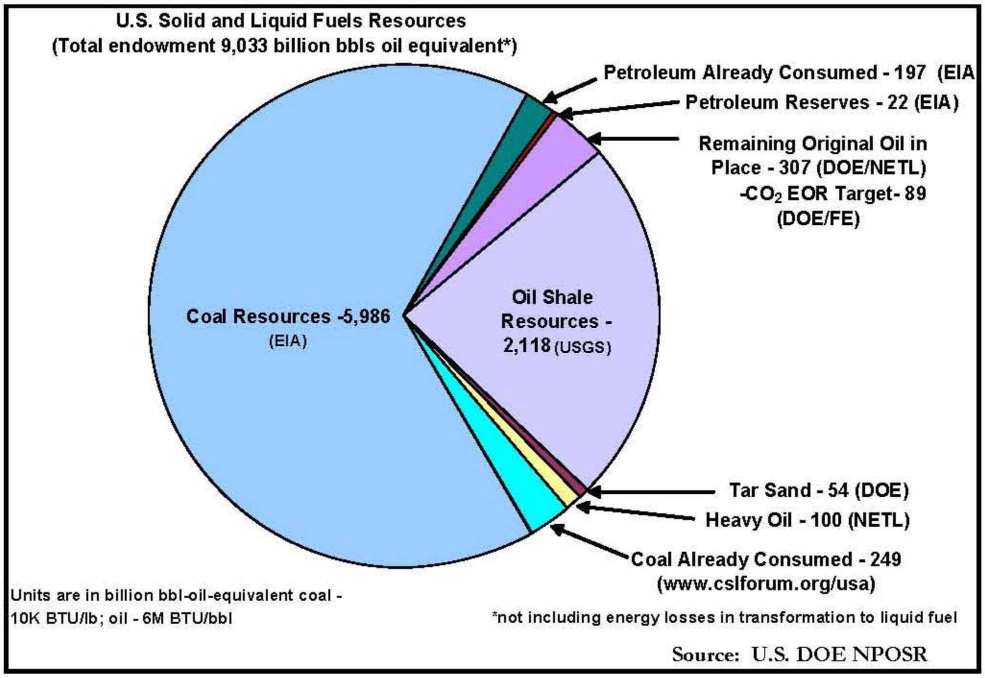
## 2.0 FUEL SOURCE OPTIONS

This section will examine the status of the primary energy sources that can supply aviation fuel to work toward security and cost stability.

Figure 5 gives a graphic picture of the U.S. solid and liquid fuel baseline. It explains much of the current posture and of the challenges we face.



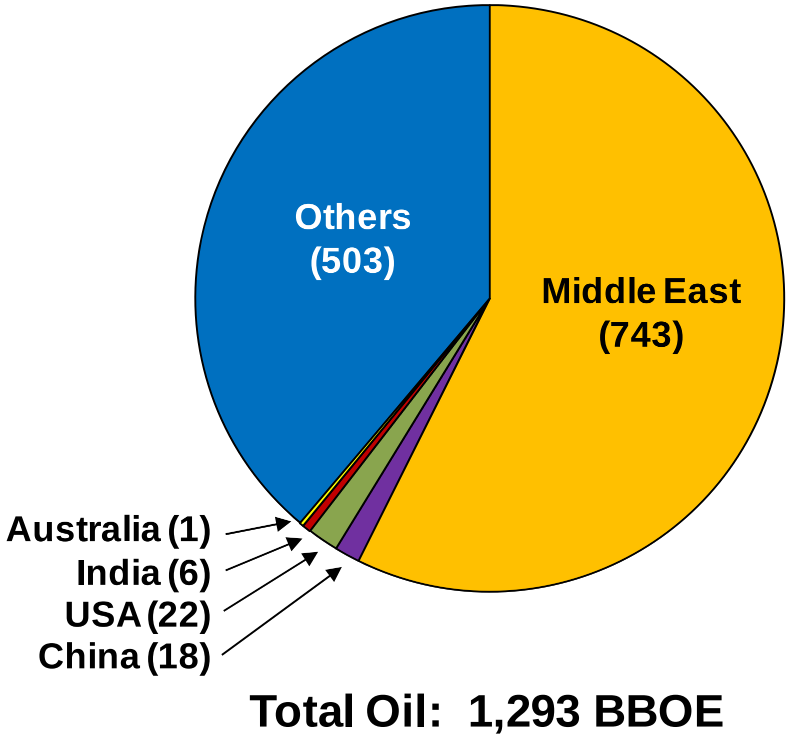

America's Strategic Unconventional Fuels, Vol I, Page I-14

**Figure 5. America's Original Endowment of Solid and Liquid Fuels Resources**

Obviously, coal is a dominate resource that, from a quantity perspective, we have only begun to exploit. Petroleum has served us well and with enhanced recovery methods, still provides options. The elephant in the room is oil shale. The heavy crude that oil shale yields is particularly suited to aviation fuel. The new technologies being developed may hold the key to the cost and extraction barriers that have made it up to now, too hard.

### 2.1 Oil

Figure 6 shows the world oil reserve picture and emphasizes the relative quantity problem that both the U.S. and China face.




Source: EIA, International Energy Annual 2005 (1 ton coal is equivalent to 2 BBOE) and Oil and Gas Journal, January 2006.

**Figure 6. World Oil Reserves**

Recoverable U.S. reserves are estimated to be between 21 and 30 billion barrels. The DOE EIA's 2008 *World Proved Reserves* shows the world total is 1, 238 billion barrels.

The U.S. produces approximately 5 million barrels per day. (6 % of world production) The 2008 production was 4.95 million barrels per day, which was essentially a linear decrease from a production high of 9.64 million barrels per day in 1970. [1]

The U.S. consumes about 21 million barrels per day or 24% of the world's 86 million barrels per day consumption. The 2008 consumption was 19.49 million barrels per day, which represents an increase from a recent low of 15.23 in 1985 to a peak of 20.80 in 2005, followed by steady declines since. [2]

In 2008, the U.S. used a total of 563 million barrels of kerosene-type jet fuel, of which 37.6 million barrels were imported as finished product. [3]

Figure 7 shows the history and projected future of U.S. production, import, and consumption of all petroleum products.

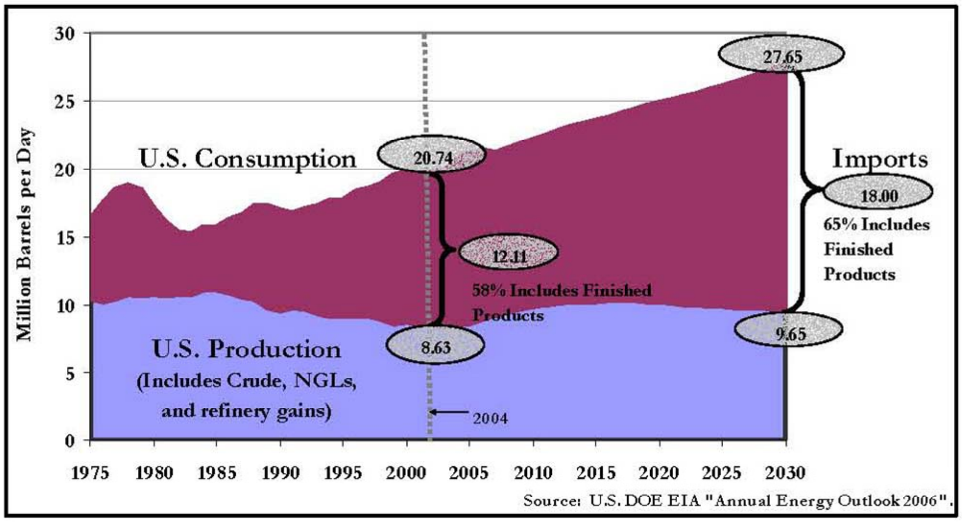



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**Figure 7. U.S. Liquid Fuels Demand**

Petroleum products derived from conventional crude oil contribute more than 50% of the total end-use energy deliveries in the United States and more than 95% of all energy used in the transportation sector. Emissions from the consumption of petroleum account for 44% of the nation's $CO_2$ emissions, with approximately 33% of the national $CO_2$ emissions resulting from petroleum use for transportation. [4]

Transportation sector emissions are divided – gasoline 59%, diesel 23%, jet fuel 10% and other 8%.

Although the DOD is the single largest user of energy in the nation, it's requirement is small relative to the total market. In perspective, DOD's recent wartime petroleum consumption has been slightly larger than a major airline.

The IEA and EIA projections of possible crude oil prices in the next twenty years vary from $35 to $94 per barrel. [5]

Today, the lower 48 states produce roughly half of the oil they produced in 1970. In 2005, Robert Hirsch produced a study for the Atlantic Council called "Peaking of World Oil Production: Impacts, Mitigation and Risk Management." [6] He compared twelve expert projections of when global peak oil would occur. They ranged between 2006 and 2025 or later. In February 2007, the GAO published a study analyzing 22 studies on peak oil conducted since 1996 – most predict peak oil to occur between now and 2040. [7]

A Texas company, Hyperion Refining, is seeking permits to build a $10 billion refinery in South Dakota. It would process 400,000 barrels per day of Canadian tar sands crude to produce low-sulfur gasoline and diesel fuel. The plant would be among the cleanest and environmentally friendly in the world, and would be the first new site refinery in the U.S. since 1976. This project is being strongly opposed by environmentalists because it would increase GHG emissions. [8]

Rob Routs, Executive Director of Oil Products and Chemicals, Royal Dutch Shell, made a presentation at Cornell University in March 2008. He said, "Conventional oil and gas – the

staples of our energy diet today – are becoming harder to find and produce. There are still large amounts of hydrocarbons in the ground …. but the stuff that's left tends to be concentrated under very deep oceans, very thick ice or very difficult governments." [9]

The April 22, 2009 NETL publication, *Balancing Climate Change, Energy Security and Economic Sustainability*, [10] summarizes a number of recent NETL studies and draws some interesting conclusions about mandates in the Energy Independence and Security Act of 2007 (EISA 2007). Section 526 of EISA 2007 prohibits any federal agency from procuring a synthetic fuel that has a GHG footprint greater than the equivalent petroleum fuel. The key findings were:

- 52% of the crude oil imports in 2008 were above the EISA 2007, Section 526 petroleum life cycle GHG emissions limit.
- In 2008, the U.S. spent $172 billion on crude oil imports that would not meet Sec 526.
- Coal-to-Liquid (CTL) Fuel with Carbon Capture and Storage (CCS) would have lower life cycle GHG emissions than 97% of all imports to the U.S. in 2008 with an associated foreign expenditure of $317 billion.
- CTL with CCS produces diesel with 5-12% lower GHG emissions than the 2005 petroleum baseline, hence well below the Section 526 requirement.
- Co-gasifying, 8% by weight, non-food source biomass with coal produces diesel fuel with life cycle GHG emissions 29% below the 2005 petroleum baseline.

Figure 8 shows the relationship between various crude imports and the EISA Section 526 requirement.

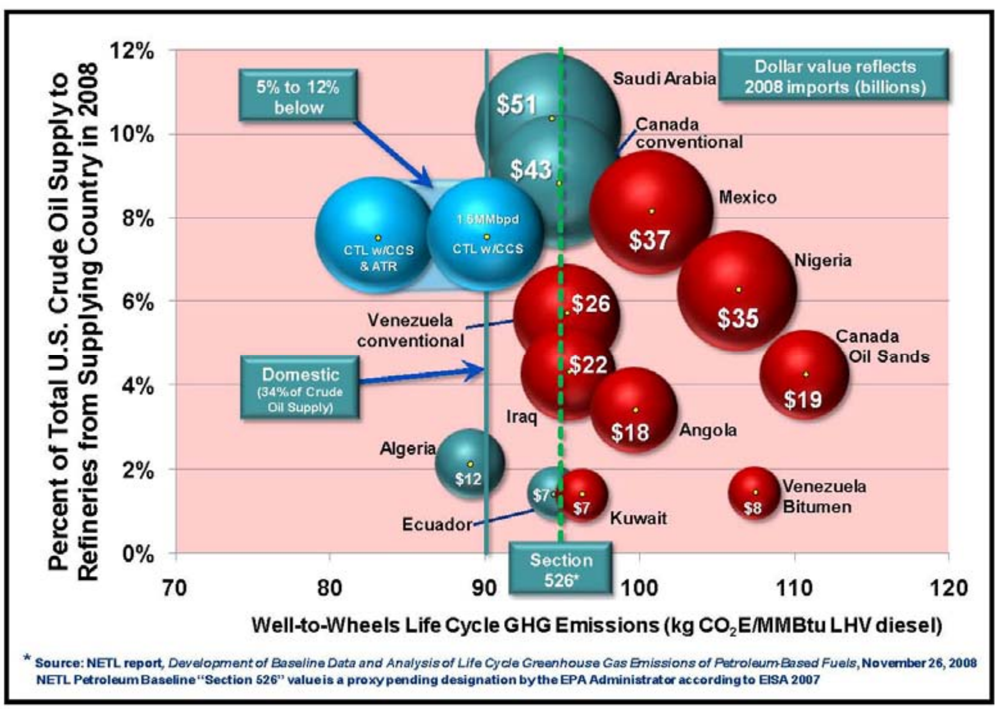


**Figure 8. Crude Oil Imports and Their GHG Emissions**

Oil is the foundation and baseline of our transportation and transportation fuels systems. Although several important non-petroleum initiatives are being investigated, there is to date no energy source that offers a near term straight forward aviation fuel solution.

**Tar Sands**

Tar sands (also known as oil sands) is a material consisting of clay, sand, water, and bitumen, a heavy black viscous oil. The U.S. has oil sands reserves located nine states, with the State of Utah alone representing a measured and speculative resource of 12-19 billion barrels of oil.[11] Utah is currently supporting research at the Utah Heavy Oil Center at the University of Utah. This research includes investigations into the nature, quantity, and characteristics of oil shale, tar sands, and heavy oil fuels. Moreover, the research will address technologies that may be emerging.[12] The extraction of the bitumen and its subsequent refining into various fuels and oils is a well established process in Canada and is done on a full scale commercial basis. Approximately 90% of Canada's oil sands produced crude is exported to the U.S. for further refining. Canadian oil accounts for approximately 20% of total U.S. oil imports. To date, there is no U.S. commercial industry producing oil from tar sands. Although a number of attempts have been made to exploit tar sands deposits, low oil prices coupled with social and environmental barriers led to the termination of most projects between 1980 and 2000.[13] Based on the potential quantities of recoverable oil, tar sands should be a key consideration as a domestic source to meet DOD and AF needs.

**Oil Shale**

U.S. oil shale crude is a huge prize, if economic and environmentally friendly extraction processes can be developed. The quest that has been underway for many years still faces many barriers but is showing significant signs of progress. When considering solutions to satisfy the Air Force security and economic stability objective, options like oil shale must stay on the table. The Task Force on Strategic Unconventional Fuel, formed by direction of the Energy Policy Act of 2005, supports this position. [14]

The federal government estimates that 800 billion barrels of oil, triple the known reserves in Saudi Arabia, are contained in Rocky Mountain area oil shale. [15]

Remember, the current estimate of the traditional U.S. crude proven reserve is 21-30 billion barrels and annual U.S. consumption is 26 million barrels per day. (9.5 billion barrels per year).

Western U.S. oil shale is carbonate rock very rich in organic sedimentary material, which being geologically younger has not yet converted to crude oil. The material, called "kerogen", can be converted to superior quality jet fuel, diesel, and other high value products. The kerogen content can range from 10 to more than 60 gallons of oil per ton of shale. Approximately 1.8 trillion barrels of shale oil, of a concentration of more than 15 gallons per ton, are estimated to exist in relatively compact areas of Colorado, Utah, and Wyoming. Interestingly, this is ten times the density found in the Canadian Alberta oil sands. The U.S. government owns and manages 80% of those lands.

**Table 4. U.S. Oil Shale Resources**

| Deposits | Richness (Gallons/ton) | | |
|---|---|---|---|
| Location | 5 - 10 | 10 - 25 | 25 - 100 |
| Colorado, Wyoming & Utah (Green River) | 4,000 | 2,800 | 1,200 |
| Central & Eastern States | 2,000 | 1,000 | NA |
| Alaska | Large | 200 | 250 |
| **Total** | **6,000+** | **4,000** | **2,000+** |
| Source: Duncan, and others (1965) | | | |

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Optimism about conquering development challenges has been greatly encouraged by the success of the Canadian government-industry partnership in bringing Alberta oil sands crude to market. The following chart is the potential oil shale yield profile determined by the Task Force on Strategic Unconventional Fuel.

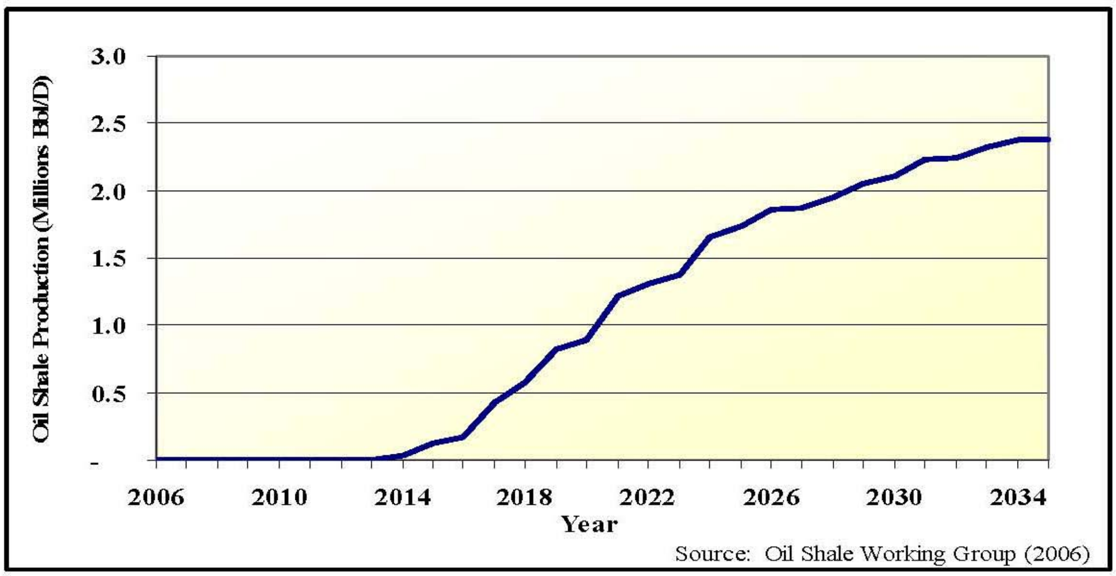


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**Figure 9. Potential Shale Development Schedule**

## 2.2 Coal

Coal can conceptually take the place of oil as a source of aviation fuel. Using processes discovered more than a hundred years ago, coal provided much of the fuel for Nazi Germany, is today providing a major portion of high quality liquid transportation fuel for South Africa, and is a significant component of China's transportation fuel future.

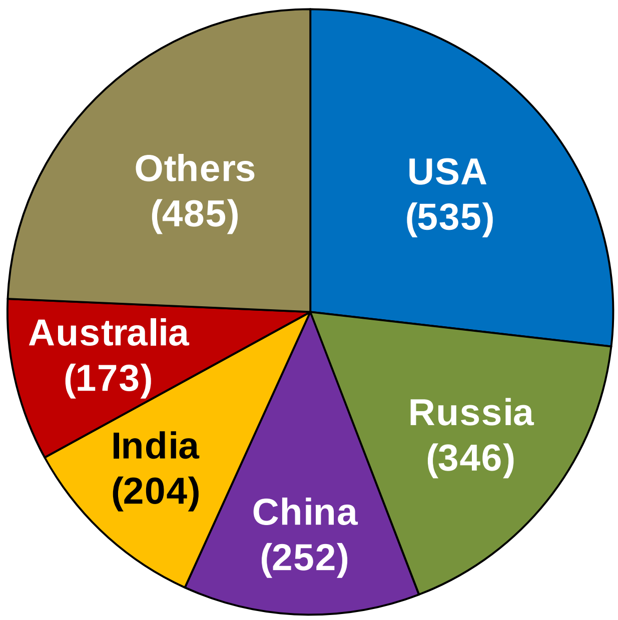
Coal has always been a major source of energy. In the past five years, it has been the world's fastest growing energy source, it produces 41% of the world's electricity, and is expanding its

contribution to the liquid fuel supply. On a total energy basis, coal today provides approximately 80 % as much energy as is provided by oil.

The world's total coal consumption in 2005 was approximately 6.5 billion tons. The U.S. used 1.125 billion tons (17 percent of the world total), 90% of it to generate 49% of our electric power. The global increase from 2000 to 2005 was 27 percent [16] and a foreshadowing of the additional 50% increase EIA projects for coal use in the next two decades – much of it in China and India.

Coal and the potential for coal-to-liquid fuel is particularly important to the U.S. because 27% of the total known world coal reserve is located here and, if converted to the appropriate forms, could supply the country's total energy needs – heat, electricity and liquid fuel - for more than a hundred years. Coal is expected to be a major source in meeting the increasing energy demand projected for the U.S.

Figure 10 shows the estimated distribution of world coal reserves in terms of billion barrels of oil equivalence.




**Total Coal: 1,995 BBOE**

*Source: EIA, International Energy Annual 2005 (1 ton coal is equivalent to 2 BBOE) and Oil and Gas Journal, January 2006.

**Figure 10. World Coal Reserves**

The processing or use of coal must take into account its varying characteristics. The different types of coal are called "ranks" and because the differences are so important, a design or process description usually refers to a specific type or even a specific mine, e.g. Illinois # 6 or Pittsburgh # 8. A coal-to liquid fuel application is especially sensitive to the energy and moisture content of

a particular coal type and to the significant cost difference the different types command. Table 5 and Figures 11, 12, and 13 show characteristics, cost history, quantities, and geographical location.

**Table 5. Regional Coal Characteristics**

| Region | Reserves, Billion Short Tons | Btu/lb, HHV | Mineral Matter, % | Sulfur, % | Moisture, % |
|---|---|---|---|---|---|
| Bituminous Coal Appalachian [a] | 19.3[f] | 13,404 | 9.1 | 2.15 | 1.7 |
| Bituminous Coal Midwest [b] | 38.2 | 11,000 | 14.3 | 4.45 | 8.0 |
| Sub-bituminous West[c] | 21.8 | 8,426 | 6.3 | 0.45 | 28 |
| Sub-bituminous[d] | 2.5 | 7,800 | 9.0 | 0.2 | 27 |
| Lignite Southwest (Texas)[e] | 9.95 | 7,900 | 9.0 | 0.59 | 30 |
| Lignite North Dakota[f] | 6.9 | 7,800 | 8.2 | 0.69 | 27 |

a Argonne National Laboratory Premium Coal Sample Bank (Pittsburgh #8), http://www.anl.gov/PCS/
b NETL, "Quality Guidelines for Energy System Studies", 2-24-04 (Illinois #6)
c NETL, "Quality Guidelines for Energy System Studies", 2-24-04 (Wyodak)
d Usibelli Coal Co. web site, http://www.usibelli.com/specs.html
e Wilcox seam, from SNG paper.
f Benson, S.A. Mitigation of Air toxics from Lignite Generation Facilities, Energy & Environmental Research Center, 1995

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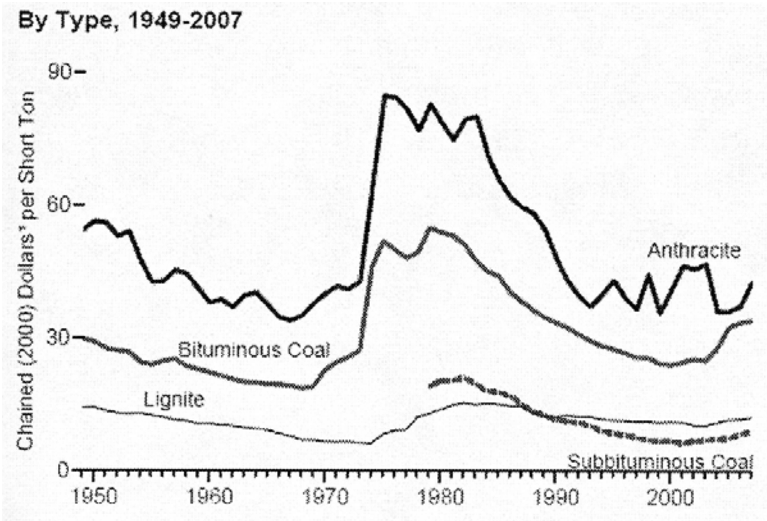
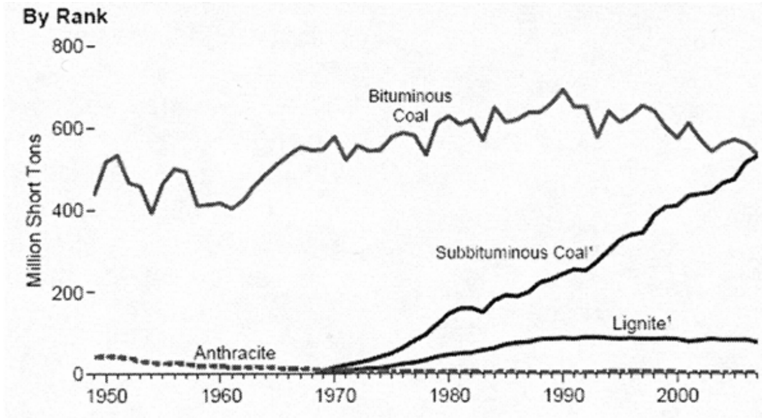
About 45% of U.S. coal is bituminous and less than one billion tons are high energy content anthracite. Table 5 shows typical characteristics of coal by it's type or rank.

Figure 11 shows the price history by rank.



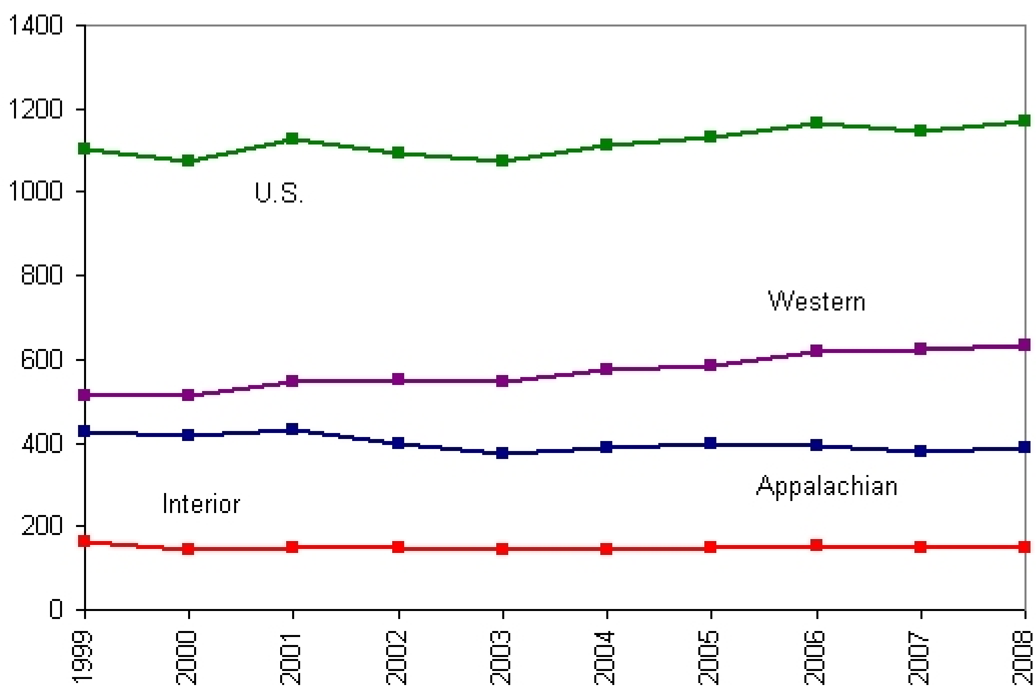

Indiana Coal Report 2009 (2-9)

**Figure 11. U.S. Coal Prices by Types, 1949-2007**




Indiana Coal Report 2009

**Figure 12. U.S. Coal Supplies for 1947-2007**
**(Million Short Tons)**




Sources: Energy Information Administration, *Quarterly Coal Report,* October-December 2008, DOE/EIA-0121

Indiana Coal Report 2009

**Figure 13. Coal Production by Region, 1999-2008**
**(Million Short Tons)**

Approximately one third of U.S. coal is surface mineable and two thirds requires underground mining. [17]

DOE estimates that a typical 32,000 barrel per day coal-to-liquid fuel (CTL) plant would use approximately 16,000 tons per day (6 million tons per year) of bituminous coal or twice that amount of low energy content lignite. [17] Thus, a single facility could supply the Air Force synthetic fuel objective of 26,000 barrels per day and would increase the annual demand for bituminous coal by approximately 1 percent, if built in a region, like the Midwest, where bituminous coal is available.

A CTL industry providing 1.5 million barrels per day or 10% of the annual U.S. transportation fuel need, would require 47 of these plants or nineteen 80,000 barrel per day plants. This quantity of fuel would use approximately 280 million additional tons (25%) of coal a year. The National Coal Council estimates that the annual coal production of 1.1 billion tons could, if required, be increased to as much as 2.4 billion tons by 2025, but would require major investment. [18]

A 2008 RAND Research Brief, *Assessing a Coal-to-Liquids Fuel Industry in the United States,* suggests that a CTL industry providing 15% of the U.S. oil demand could generate direct economic profits of $20-60 billion a year at oil prices from $60-100 per barrel. They project that each barrel of CTL fuel could provide a net social benefit of between $6 and 24 a barrel. [19]

The current concern about greenhouse gas emissions is focusing increasing pressure on coal because of the history traditional powdered-coal electricity generation plants have for venting large quantities of carbon dioxide, mercury, and sulfur. Technologies have been developed to limit these undesirable emissions, but prohibitive retrofit costs have delayed full implementation until the next generation of plants. Environmentalists have blocked the construction of more than ninety traditional and new technology plants since 2002. The lack of a clear regulatory structure and a GHG control process has greatly slowed construction of the badly needed new technology clean-coal plants. The 2007 MIT study, *The Future of Coal*, strongly recommends that business not take the risk of designing and building new power generation plants until the rules and policies are defined and implemented. [20]

### 2.3 Nuclear

The nuclear industry is included here to highlight some indirect connections. The construction of a coal-to-liquid fuel facility has many things in common with nuclear power – multi-billion dollar capital cost, a several year planning and construction lead time, public resistance, and the use of similar very large pressure vessels manufactured by only a few (non-U.S.) companies. And, the co-location of a nuclear plant and CTL plant could reap significant benefits for both.

The generation of electricity with nuclear power began in the 1950s. The first commercial plant was in England in 1956 and the first U.S. plant in Shippingport, PA in 1957. Today, there are 449 nuclear power reactors in 31 countries, supplying 17% of the world's electricity. [DOE Office of Nuclear Energy] The U.S. gets 19% of its electricity from 104 plants that produce 100 GW, which is almost a quarter of the world's total, nuclear provided power. Japan is second with 78 GW and France third with 63 GW. [21]

There are currently seventeen Combined Construction and Operating License applications for 26 reactors under review at the U.S. Nuclear Regulatory Commission, with seven more close behind. Three early site permits have been issued. Two reactor designs covering 14 of the 26 submitted applications have been certified, with four more under review. Twenty one plant locations have been announced.

It is expected that several of these new plants will be under construction by 2010 and as many as eight in operation by 2016. Worldwide, there are 350 reactors proposed or planned with forty now under construction in eleven countries. Seventy plants are expected to become operational in the next 15 years according to the International Atomic Energy Agency. The World Nuclear Association estimates that once the construction gets underway, a new 1,000 MW unit will be completed every five days.

This development will provide a significant amount of clean electricity to meet the expected demand, reducing the requirement for coal. The very limited manufacturing capacity exists to produce the forged containment vessels and related components for these plants poses a challenge. Japan Steel Works produces only four vessels a year and although several companies are getting back into the business, a limiting bottleneck will exist. Since no U.S. plant construction has been started since 1977 and none have been licensed in more than 30 years, there is currently no industrial capacity in the U.S. to produce such heavy forgings. [22] This industrial deficiency is relevant to the construction of coal-to-liquid or natural gas-to-liquid fuel plants because many of the same type of large, heavy components are required. A build-up of this manufacturing capability and the large-scale facility experience gained from the nuclear plant construction will, in the long-term, reduce risk and cost to coal and gas–to-liquid fuel facilities. However, the waiting line may be long. The Air Force synthetic fuel objective is not large enough to jump this line without special incentives.

A potential collaboration between nuclear power generation and coal-to-liquid fuel production has been proposed by a number of scientists, including Dr. Charles Forsberg from MIT. Use of the waste heat and of off-peak electricity from a nuclear reactor would solve problems for both facilities. An independent source of hydrogen and heat would make CTL more efficient and significantly reduce $CO_2$ production. A hybrid system could reduce coal use by 70% relative to traditional CTL processes. [23]

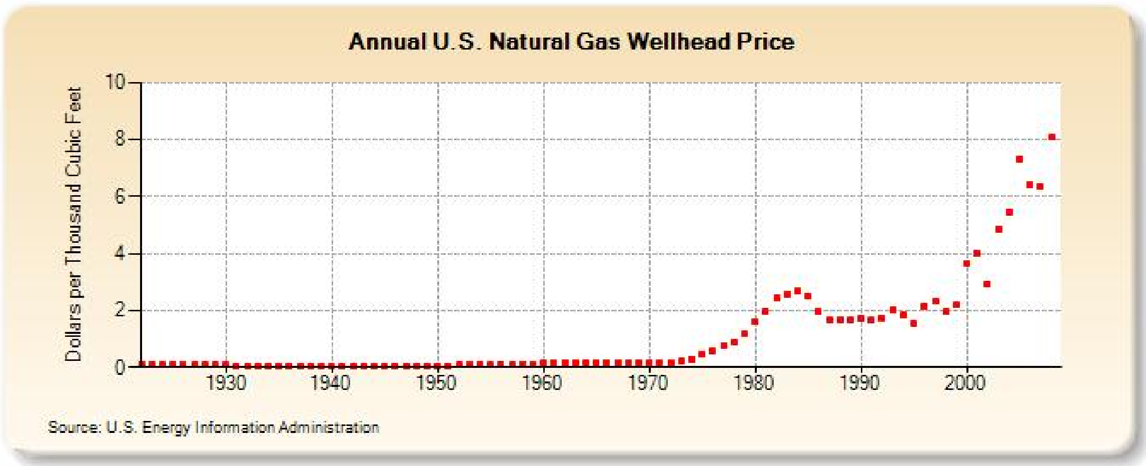
### 2.4 Natural Gas

Natural gas has become the feedstock of choice for gas-to-liquid fuel (GTL) Fischer Tropsch fuel production in several countries. To this point, the natural gas found co-located with oil or in locations where transportation in gaseous form is difficult, has been flared (burned) or abandoned. Being converted to liquid fuel gives it significant value and makes it easier and much safer than LPG to transport. Section 4 will examine these facilities in detail.

Natural gas could be the quickest, lowest risk, and lowest capital cost source of synthetic aviation fuel - with a much lower $CO_2$ emissions than coal.

The down side is that natural gas, for these very reasons, has become popular. The U.S. now gets 22% of its electricity from natural gas even though it costs four times as much as electricity produced by coal-fired plants. The use of natural gas for power generation has expanded significantly because of its flexibility to come on-line quickly to fill demand gaps. This advantage is expected to cause an even greater demand in order to fill the greater gaps inherent to the variability of wind and solar electricity generation. Although new discoveries have been made and new extractions technologies have been developed, the U.S. now imports 19% of its natural gas.

Figure 14 shows that the popularity has affected cost.




EIA National Gas Navigator

**Figure 14. Annual U.S. Natural Gas Wellhead Price**

## 2.5 Bio Fuel

A promising energy source gaining new emphasis is biomass. It comes in many forms – grains, plant fiber, plant oils, animal fats, wood, waste materials, and even bacteria and algae. Fuels are produced by many different technologies and have many different advantages. The U.S. has considerable experience with corn grain ethanol and is quickly moving to other forms that have even greater potential.

The old way of converting biomass into energy, that has been used for thousands of years, is to burn it. Heat can be used directly to drive turbines and generate electricity or by using controlled combustion processes, it can be thermochemically transformed to a hydrogen-carbon gas and then to transportation fuel.

Much of the recent consideration of biomass has been as an enabling companion to coal. The co-firing of biomass with coal in a gasification plant has been widely recommended as an efficient way of reducing the life-cycle assessment carbon footprint and meeting the EISA 2007 Section 526 carbon footprint requirement. Dr. Robert Williams, Princeton Environmental Institute, Princeton University, and many others, have done extensive research to show that the addition of even 5 or 10% biomass provides a very cost-effective method of obtaining environmentally friendly carbon footprint levels. This collaborative approach provides a solution to the coal GHG problem and to the biomass land use and limited yield problems. [24]

A 2007 NETL study, *Increasing Security and Reducing Carbon Emissions of the U.S. Transportation Sector: A Transformational Role for Coal with Biomass* [25] examines the benefits of co-firing coal and biomass and illustrates the huge scale challenge associated with biomass. A table detailing the study findings for a number of biomass types, quantities, and land use factors is included in Appendix B and summarized here with an example.

The study examines a number of cases. The base case considers a 7,500 barrel per day plant using 4,589 tons per day of Illinois # 6 coal and 510 tons per day of poplar. The NETL table shows that 500 tons per day of popular tree material would require annual acreages of 36,135, a total area considering land use accommodations of 706 square miles and average delivery distances of 19 miles. Switchgrass resulted in similar requirements and corn stover, acreages of 91,250. Remember, the Air Force synthetic fuel goal is 26,000 barrels per day.

Several chemical processes are used to convert fats and vegetable oils like soy, camellia, jatropha, or algae oil to synthetic fuels like soy diesel. These same processes could also be used on fiber and cellolistic components that are normally combusted

An initial analysis of the oil sources would seem to indicate that they pose a production, collection, and processing challenge to generate large volumes of fuel. The following table gives examples of current yields for some of the promising sources. Significant research is in process and hopefully will lead to notable yield improvements.

**Table 6. Current Biomass Yields**

| Source | Gals/Acre/Year | BTU/Gal | Cost/Gal |
|---|---|---|---|
| Camelia | 54 | 185,000 | $ 10.00 |
| Jatropha | 200 | 140,000 | $ 28.00 |
| Algae | 3,500 | 130,000 | $ 455.00 |
| Crude Oil | --- | 138,000 | $ .90 |

Virgin Atlantic, in 2008, used 5% biofuel during a flight from London to Amsterdam – approximately 220 miles. The biofuel for that one flight required 150,000 coconuts as well as babassu nuts. [26]

In another set of emerging technologies, bacteria, yeasts, and enzymes are used to biochemically break down carbohydrates to form alcohol fuels like ethanol.

**Algae-Based Fuels**

The first and second generation biofuels have important functions, but as pointed out above, at today’s technology levels they do not appear suited to become a stand alone high volume petroleum or coal-based jet fuel substitute. The most encouraging possibility is algae-based fuels.

The DOE released a Request for Information (RFI) on June 3, 2009 that solicits comments on a draft version of the *National Algal Biofuels Technology Roadmap.* [27] This 204 page document is the product of a December 2008 workshop that brought together more than 200 algae experts and stakeholders from all related disciplines and organizations. The draft Roadmap and its critique seek to define the elements and actions necessary to overcome current technical barriers and make algal fuels cost competitive with petroleum-based fuels.

The above sections have identified possible feedstock and process technologies that could lead to synthetic aviation fuel. CAAFI and the U.S. Department of Agriculture are encouraging and supporting a wide collection of possible biomass feedstock developments. Amazing progress has been made in the past five years. Breakthroughs in the next few may produce viable options.

Continental Airlines, on January 8, 2009, for the first time flew a commercial aircraft on 50/50 blend of algae-based biofuel fuel and normal petroleum based fuel. The test was uneventful and showed no perceivable differences.

### 2.6 Comparative Costs

This section has looked at several possible energy sources that are difficult to compare.

Table 7 shows the relative capital and product cost for various energy sources. The analogy of electricity generation (cents per kW hour of electricity) is used as a common base to illustrate the comparison.

Appendix [E] contains a series of charts which show capital cost and the effect of adding various levels of a carbon tax to these options.

**Table 7. Selected Capital Costs and Electricity Prices**

| Source | Cap Cost ($/kWh) | Electricity Cost (Cents/kWh) |
|---|---|---|
| Coal | $1,500 - 1,900 | 3-5 |
| Natural Gas | 450 - 550 | 4-8 |
| Nuclear | 1,500 - 3,000 | 3-6 |
| Hydroelectric | 1,700 - 2,300 | 4-6 |
| Geothermal | 1,600 - 4,000 | 4-7 |
| Wind | 1,700 - 3,400 | 8-13 |
| Concentrated Solar | 1,700 - 1,900 | 10-13 |
| Photovoltaic | 3,800 - 5,700 | 21-23 |

Source: The Future of Electricity, School of Public and Environmental Affairs, Indiana University, May 2009.

This section has reviewed the basic energy sources that could be applied to meeting the Air Force objective. Succeeding sections will examine the related technologies, constraints, and policies.

## 2.7 The Canadian Connection

### 2.7.1 Overview

The pervasive collaborative relationship that exists between the U.S. and Canada is strongly present in the production and consumption of energy.

- Both countries are relatively high energy producers and consumers
    - Production: Quadrillion BTUs per year: U.S. - 71, Canada – 19.3, Europe – 47, China- 67, World – 469 [28]
    - Consumption: Million BTU per person per year: U.S.- 334 , Canada - 427, Europe – 146, China – 56, World average – 72. [29]
- Most of Canada's energy exports go to the U.S., making it the largest source of U.S. energy imports.
- Extensive oil and natural gas pipelines interconnect the two countries enabling geographical distribution efficiency, refining efficiency, and the two way flow of specialty products.
- Electricity networks are highly integrated enabling exchange in both directions.

### 2.7.2 Canadian Energy Sources

Canada has a considerable set of natural energy resources that make an interesting comparison with those of the U.S. [30, 31]

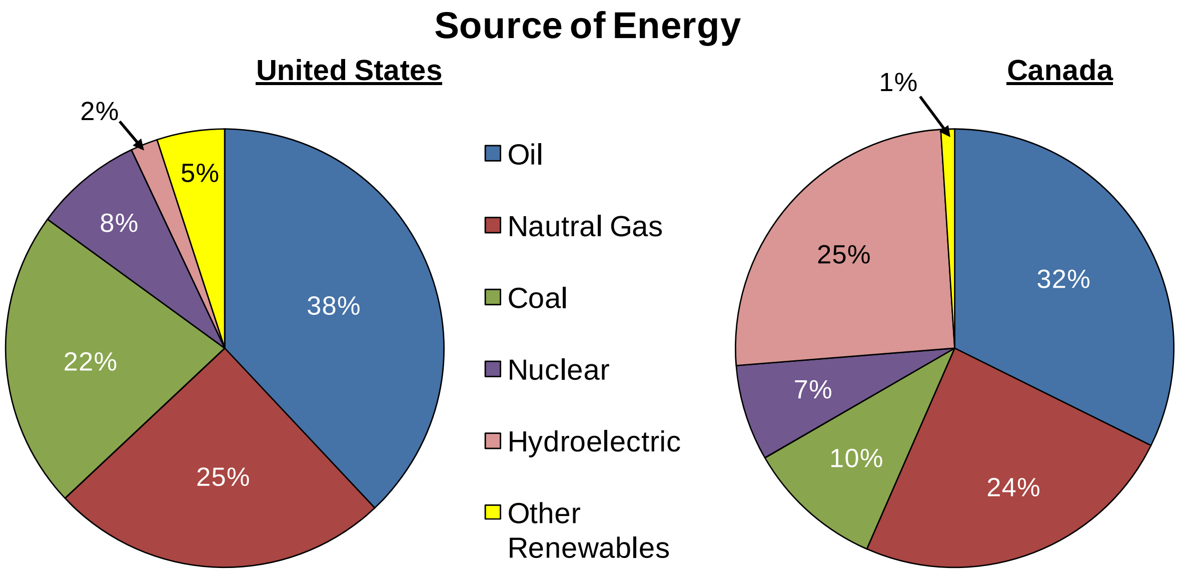



**Figure 15. Consumption Sources for the U.S. and Canada**

Important differences not shown by these charts: [31]

- Oil- the U.S. produces 8.49 million barrels per day but consumes 20.6 million barrels per day
- Oil-Canada produces 3.35 million barrels per day but consumes 2.32 million barrels per day and exports a million barrels per day – most of it to the U.S.
- Oil reserves- The U.S. has approximately 22 billion barrels of traditional petroleum reserves; Canada has 173 billion barrels of proven reserves, second only to Saudi Arabia – but 95% of these reserves are oil sands deposits in Alberta.
- Natural gas – the U.S. (2008) produced 20.6 trillion cubic feet and consumed 23.2 trillion cubic feet
- Natural gas – Canada produced (2007) 6.6 trillion cubic feet and consumed 3.3 trillion cubic feet. In 2008, 3.6 trillion cubic feet was exported to the U.S.

### 2.7.3 Oil Sands

In 2008, approximately half of Canada's crude oil production came from oil sands. [31] This output is expected to grow. Oil sands have always represented an opportunity and a set of challenges. Canada's huge oil sands reserve and relatively small amount of traditional crude demanded that the oil sands be considered. Standing in the way were the significant emissions associated with separation cell processing of the open pit mined bitumen and the substantial amounts natural gas and water required for the processing. A concerted partnership between

government and private industry has developed a set of technologies that today support a viable, cost effective, and environmentally improved industry. An interesting example of U.S.-Canada collaboration is the shipment of U.S. light crude by pipeline to Canada for use in diluting the oil sands crude to make it pipeline compatible. Canada continues to focus resources on improving oil sands effectiveness and efficiency.

Nexen, a major Canadian-based global oil and gas company, focuses on oil sands, [31, 32] unconventional gas, and deep water projects. In 2008, Nexen brought the Long Lake project on-line. This is an improved technology in situ project that uses the steam-assisted gravity drainage process. It is the first oil sands project committed to not using surface water or large amounts of natural gas. The 81 well-pairs are producing premium synthetic crude with operating costs of $5-9 per barrel and expect to reach a production level of 60,000 barrels per day.

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## 3.0 INTRODUCTION TO TECHNOLOGY SOLUTIONS

Section 2 discussed the various sources of energy that could be used to generate synthetic fuel. This section will discuss the actual processes that currently exist or are being developed to produce synthetic fuels from these various sources. The overall approach and the specific steps in these processes are driven by the energy source chosen for conversion. The selected energy source is commonly referred to as a feedstock. Looking back on Section 2, we find the feedstock can be coal, natural gas, forms of petroleum found in tar sands and bitumen shale, and various biological sources.

Feedstocks can be used singly or can be combined. The feedstock selected can influence what process steps are required. Based on types and amounts generated, requirements to control greenhouse gas emissions can also determine processing steps. There are some basic, common elements or steps of conversion that apply:

- Feedstock preparation
- Feedstock processing
  - Indirect conversion used for a variety of feedstocks
    - Steps
      - Gasification to produce synthetic gas (syngas)
      - Processing of syngas to remove impurities and improve the hydrogen-carbon ratio
      - Reactor processing of syngas to produce synthetic crude or fuels
    - Output- synthetic crude that goes to traditional refining to produce common fuels
  - Direct conversion used primarily with coal as the feedstock
    - Can be a single step that produces various synthetic fuel or crude
    - Output- synthetic crude for refining or “ready to use” fuels
- Greenhouse gas capture and disposition

Processes are named primarily based on feedstock and processing approach:

- Coal-to-liquid fuel (CTL) indirect Fischer-Tropsch
- Direct coal-to-liquid (DTL) Berguis
- Gas-to-liquid fuel (GTL) natural gas Fischer-Tropsch
- Methanol-to-liquid (MTL)
- Bio-to-liquid (BTL)
- Mixture of coal and biomass to liquid fuel (CBTL)

What follows is discussion of the various processes and feedstock applications. Since gasification is common to many approaches, it is addressed first.

## 3.1 Current-Near Term Options

### 3.1.1 Gasification

Pulverized coal is burned to produce half of the world's electricity. This simple process has produced cheap electricity since the 1920s, but unfortunately also results in smokestack emissions that put significant amounts of the trace elements found in the coal and a large amount of carbon dioxide (4.4 million tons/ year from a 500 MW plant) into the atmosphere. Our cognizance of the harmful effects of the mercury, sulfur, and nitrogen compounds and of the Greenhouse Gas (GHG) potential for climate change makes burning coal in this way no longer tolerable.

Fortunately, there is a better way called gasification. As early as 1792, Murdoch, a Scottish engineer, distilled coal in an iron retort and lighted his home with the coal gas he produced. [1] Early in the nineteenth century, gas manufactured by the distillation of coal was introduced to street lighting, first in London in 1812 and soon after in major cities worldwide.

Coal, petroleum coke (pet coke), municipal wastes, biomass, or any material containing carbon can be reacted to produce a stream of hydrogen and carbon monoxide called synthesis gas or syngas. The reaction is done at high temperature and pressure in a reactor vessel with limited oxygen to cause incomplete combustion and steam which provides a source of hydrogen. The chemistry of this process is explained in Appendix A. The nature of syngas allows for toxic materials to be easily removed.

The discussion of coal gasification today is normally associated with a process called Integrated Gasification Combined Cycle (IGCC) and is associated with electricity generation because that is and will continue to be coal's major use. A plant is called "integrated" because the syngas produced in the gasification unit of the plant has been optimized for a combined cycle. The syngas is used to fuel a gas turbine which generates electric power while the heat recovered from both the gasifier and gas turbine, instead of being wasted, is used to drive a steam turbine which also generates electric power. It is the very same gasification process that is used to convert coal to syngas as the first step of the Fischer-Tropsch fuel synthesis process. The gasification segment of a typical Fischer-Tropsch plant may account for as much as a third of its capital cost.

The gasification process produces a clean compressed stream of carbon dioxide that can be easily controlled and stored. This enables several productive ways of using the carbon rather than just sequestrating it. The cost of carbon capture from the gasification process is also drastically less than from the old pulverized coal burning process where it must be removed from the smokestack.

During a time that a variety of factors have almost completely stopped the development of coal-to-liquid fuel plants, development of the less costly IGCC electricity plants has continued. They are badly needed to meet the high priority electrical power demand with an environmentally friendly process. As a by-product, this development continues to advance gasification technology and reduce the associated costs, thus paving the way for a lower cost and lower risk CTL future.

#### 3.1.1.1 Plasma Gasification

Although gasification is a huge improvement over burning powdered coal, its capital cost, efficiency, and carbon dioxide production leave room for improvement. A number of new processes using plasma gasification appear to offer a better way. Plasma, often referred to as the

fourth state of matter, is conductive and thus responds to electric and magnetic fields which allow the high temperatures to be obtained and focused. Plasma exists in many natural and man-made forms and is used in many ways. It is the plasma phenomenon that causes an incandescent bulb to generate light and heat and to enable several arc welding and metal cutting processes. Application of these technologies to coal, waste, and many other substances produces carbon-hydrogen syngases compatible with fuel synthesis, without many of the undesirable byproducts associated with gasification.

This is one of the emerging technologies that may be a game-changer.

### 3.1.2 Underground Coal Gasification – UCG

The underground coal gasification process has recently regained interest in Australia and the U.S. Coal reacting with limited oxygen and water in its naturally occurring underground seam produces the same hydrogen-carbon monoxide syngas product as a surface facility. The relatively simple procedure is illustrated in Figure 16.[2] Drilling two separated holes into a coal seam, connecting them through the seam, then injecting a measured amount of oxygen or air into one hole to enable incomplete combustion, allows recovery of the resultant syngas product from the second hole.

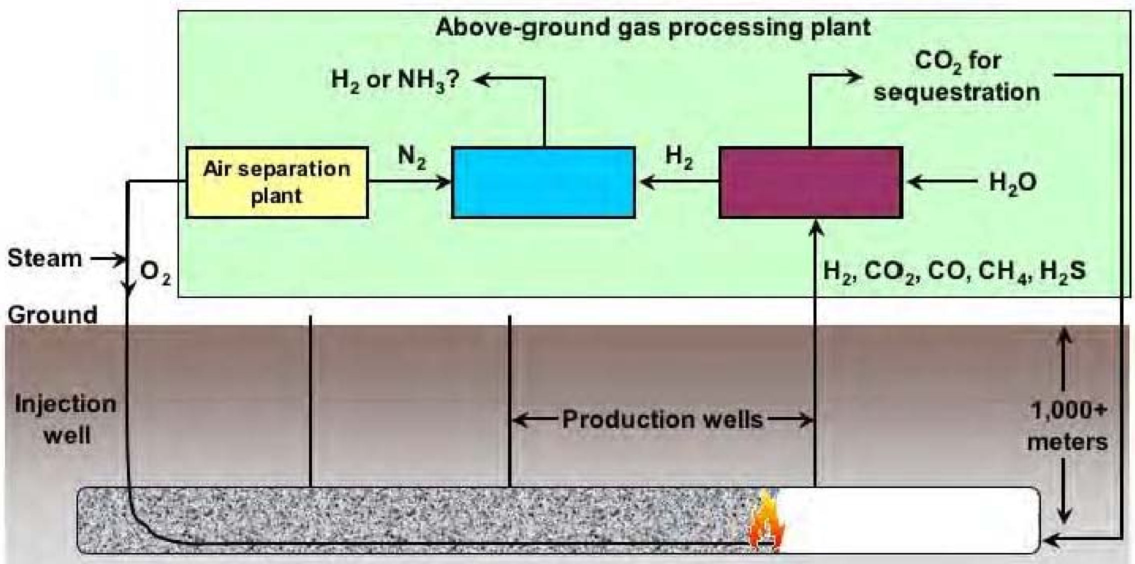



**Figure 16. Schematic of a UCG Process**
Purdue University, School of Chemical Engineering

The recent advances in horizontal drilling shown in Figure 17, have greatly enhanced oil recovery and enabled the implementation of UCG.

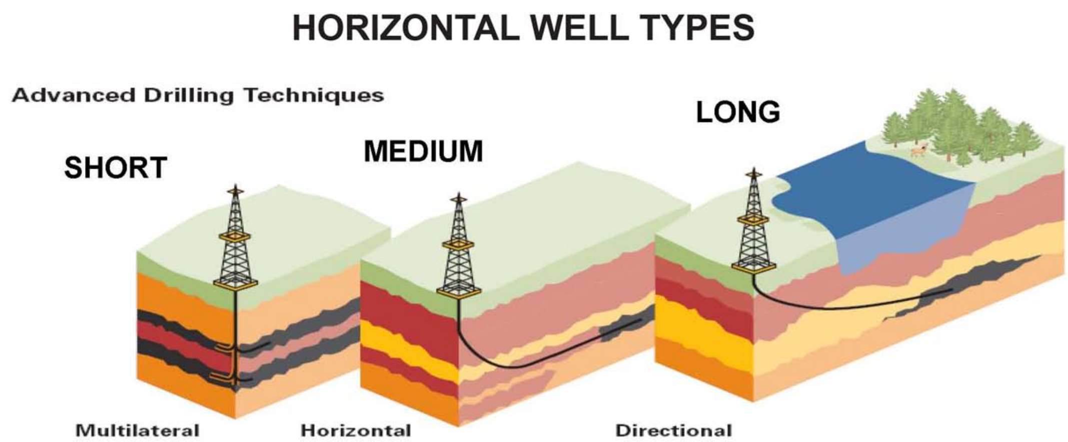



**Figure 17. Horizontal Well Types**

Underground gasification has existed in Uzbekistan for the past sixty years. Dr. Julio Friedman from the Lawrence Livermore Lab, in November 14, 2008 Congressional testimony, pointed out that research on underground coal gasification was also conducted in the U.S. between1940 and the early 1990s with especially active attention during the energy crisis that started in 1973. However, like several other alternative energy investigations, it was stopped when no longer competitive with cheap oil and gas in the mid-1980s. [3] Supported by a $350 million budget, DOE, several national labs and several industry partners conducted a program that included more than 30 field trials.

There are several important advantages to UCG. Un-mineable narrow coal seams can be used. Long time South African CTL expert Sasol has reported that recent tests preparing for a UCG demonstration facility near their Secunda plant have shown that coal extraction approaching 95% can be obtained where 37% has been the standard mining limit for many deep narrow seams. [4] Australia's Linc Energy reports obtaining nitrogen free syngas with a H2-CO ratio of 1.8 that is ideal for their GTL process and produces fuel at $25 per barrel. [5] Linc opened a 675 tons of coal per day UCG demonstration plant northwest of Brisbane Australia in October 2008 and is now producing clean F-T synthetic crude which then yields diesel and gasoline fuels. Linc has recently signed agreements to work toward UCG plants in the Red River Delta of Vietnam and in Russia. [6]

Several UCG attributes enable low cost fuel. The huge, costly and long lead gasification reaction vessels aren't necessary. A UCG operation can be constructed in 6 to 9 months rather than several years and being compact and mobile can be used in remote areas and at a small scale.

Environmentally, UCG doesn't require cutting and filling huge amounts of overburden to reach the coal. A March 2009 Federal Court decision that challenges the U.S. Army Corp of Engineers nationwide permit that enabled surface mining operations to fill adjacent valleys with overburden or material removed from mountaintops is expected to make this common practice a significant issue. [7] UCG offers a way to balance the need for coal and the need to control its emissions. [8] In addition, the often troublesome slag waste product created by many gasification processes of mined coal is left in the ground by UCG. UCG also removes many of the safety risks associated with deep mining.

### 3.1.3 Fischer-Tropsch Coal To Liquid Fuel (CTL)

The concept of chemically rearranging the hydrocarbon constituents of coal by gasification to form liquid fuel is more than a hundred years old. Many different carbon bearing materials and several different processes can be used to obtain fuels similar to those derived from petroleum. These processes are basically a matter of hydrogenation since common fuels, such as natural gas, gasoline, and aviation fuel, have a much higher hydrogen content than coal, biomass, or other carbonaceous feedstocks. The source of the added hydrogen is normally water.

The process that has become synonymous with liquid fuel from coal is Fischer-Tropsch. The statement is often made that Fischer-Tropsch (F-T) technology is very mature and easy to implement. Although true is some ways, it is not the whole story.

There are several similar chemical paths. The chemical path known as Fischer-Tropsch (F-T) indirect liquefaction is of the most interest to us because of the high quality fuel products it produces. This process is the result of work by German chemists Franz Fischer and Hans Tropsch in the1920s. By 1943, nine Fischer-Tropsch plants had been constructed in Germany. At their peak in the year of 1944 they produced a total of 4.2 million barrels or 11,500 barrels per day of oil and gasoline to support the German war effort. [1] The German F-T plants not destroyed in the war, as well as those built in Japan, Britain, and France, were soon shut down as cheap petroleum and natural gas became available.

South Africa, isolated because of apartheid policy, short of petroleum and with an abundance of coal, adopted the Fischer-Tropsch process. The Sasol company undertook the development and in 1955 opened an initial production facility. Following significant research, two co-located Sasol plants were brought on-line in 1980 and 1982. They still produce 160,000 barrels per day of fuel and until very recently were the only significant CTL plants in existence.

A typical F-T plant is shown schematically in Figure 18.

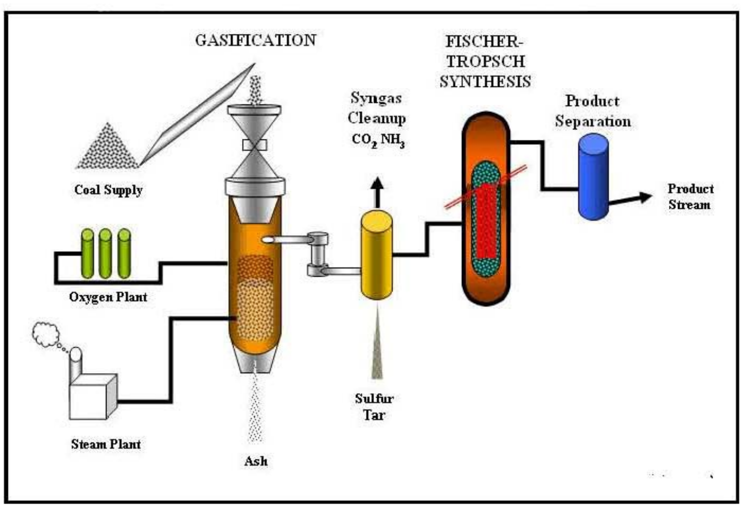



**Figure 18. Conceptual Fischer-Tropsch Plant**

The F-T process normally has an efficiency of not more than 50% with a ton of coal producing approximately two barrels (84 gallons) of fuel and 1.6 tons of carbon dioxide. The water consumed can be as much as 370-420 gallons per ton or 4 -5 gallons per gallon of fuel. [9]

The main advantage of the F-T process is the quality of fuel produced. The disadvantages are the large amounts of heat and thus extra coal required, the large amounts of water required to provide the necessary hydrogen and the large amounts of $CO_2$ produced as a by-product.

The F-T CTL process provides a synthetic crude, that when refinery upgraded, yields quality aviation fuel meeting USAF needs. The Air Force Alternative Fuel Certification Office has used Sasol produced F-T CTL fuel in their program.

### 3.1.4 Fischer-Tropsch Natural Gas To Liquid Fuel (GTL)

The F-T process reconfigures the hydrogen-carbon monoxide rich syngas in the coal-based process, to produce a liquid fuel or wax fuel base. The same process works with a naturally occurring equivalent such as natural gas and is in that case called gas-to-liquid fuel (GTL).

GTL has several advantages over the coal-based CTL. GTL has an efficiency of 75-80 %, uses a negligible amount of water because natural gas already has the desired hydrogen-carbon ratio, and produces only 0.12 – 0.14 tons of $CO_2$ per barrel of liquid fuel compared to the 0.8 tons per barrel for CTL fuel. [10]

The capital cost of a GTL plant is approximately half that of a CTL plant and the annual operating costs (without feedstock or $CO_2$ control costs) is one-third that of the CTL rate. GTL provides a profitable way of transporting out-of-the-way natural gas to market (as liquid fuel). GTL also fills a need to reduce gas flaring for economic, environmental, and legal reasons in countries such as Nigeria, which has been flaring 2.5 billion cubic feet of natural gas per day.

For these reasons, GTL has become the process of choice for synthetic fuel where reasonably priced natural gas is available.

The F-T GTL process would produce a product, that when upgraded would provide a quality aviation fuel for the Air Force. The Air Force Alternative Fuel Certification Office has used GTL fuel produced by Shell in Bintutu, Malaysia in their program.

### 3.1.5 CTL MTG – Methanol to Gasoline

A less known and more recent chemical path from coal to liquid fuel is methanol synthesis. ExxonMobil Research and Engineering developed a process than converts syngas (from coal or natural gas) to high quality clean gasoline in the 1970’s. It was put it into commercial (14,500 barrels per day) operation with a natural gas feedstock in New Zealand in October of 1985, and was operating at full design capacity very quickly. The Fischer-Tropsch process produces a broad spectrum of straight-chain paraffinic hydrocarbons that require upgrading to produce commercial quality gasoline, jet fuel, or diesel. In contrast, MTG selectively converts methanol to one liquid product which is a very low sulfur, low benzene regular octane gasoline.

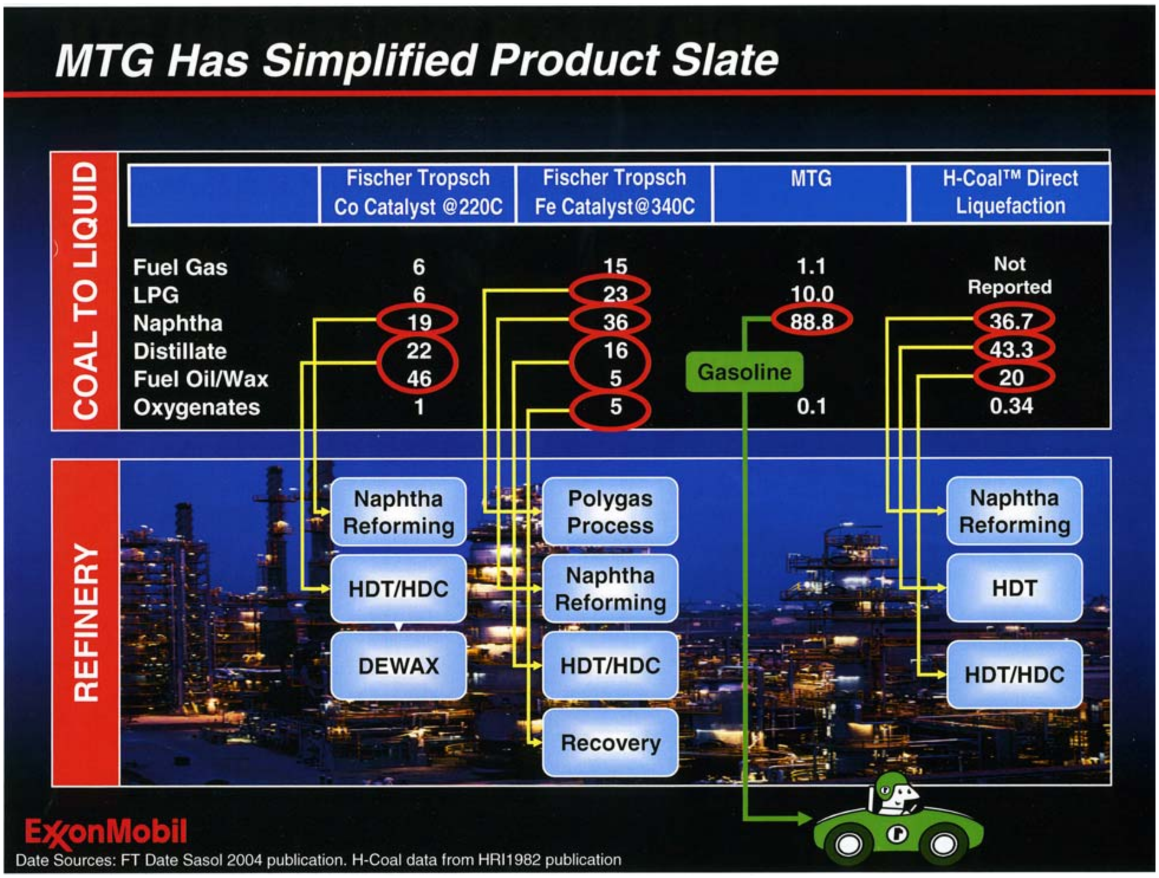



**Figure 19. MTG Products**

The MTG product is directly and fully compatible with refinery gasoline and thus is often in demand for blending to reduce sulfur or benzene levels in the petroleum-based products. It can also be distributed directly. About 90% of the hydrocarbon in methanol is converted to gasoline with the remainder being primarily LPG. Although MTG, like the other CTL processes, is very dependent on specific catalyst characterization, its scalability and start-up record has been much better than what the F-T cousins have experienced. The operation is very predictable and stable with very little variation in the product. There is, thus, very little technical or scale-up risk.

The recent interest in using coal as a fuel source and the high cost of F-T facilities has heightened market interest in MTG technology. Based on the ten year New Zealand experience, improvements have been made to reduce both capital and operating costs. The second generation technology incorporates significant improvements that reduces the number of heaters, the size of the heat exchangers, and the compressor requirements. These improvements reduce capital cost by 15-20 percent. [11]

The MTG product would not provide a satisfactory aviation fuel since it is difficult and costly to upgrade.

### 3.1.6 DCL – Direct Coal Liquefaction

Direct Liquefaction is another chemical reconfiguration path from coal to liquid fuel.

It was developed in 1917 by Fredrick Bergius in Germany and was taken to an even larger commercial level than F-T by Nazi Germany. In 1944, twelve direct-liquefaction plants produced 23 million barrels per day of automotive fuel. Remember, the AF's 2016 objective is 26 thousand barrels per day).

Two demonstration plants were built in the U.S. in the 1970s as part of an extensive DOE evaluation, but in the late 1980s, the project was terminated as non- competitive with low cost petroleum fuels.

In the first significant DCL activity since the 1980s, a 20,000 bpd plant built by the Chinese Shenhua Coal Group was commissioned in December 2008. It experienced a widespread hardware failure after only 303 hours of check-out operation and is undergoing refurbishment. [12]

Direct Liquefaction has a higher conversion efficiency, a lower capital cost, uses less water, and thus produces less $CO_2$ than indirect F-T. The product from traditional DCL has normally been of a lower quality that could not be easily and economically purified to provide aviation grade fuel without significant refining upgrades. Several companies, including the University of Witwatersrand's Centre of Material and Process Synthesis (COMPS) in Johannesburg, who built the Chinese plant, claim to have developed an improved process which may overcome these disadvantages. [13]

### 3.1.7 Biofuel

#### 3.1.7.1 Biofuel Background

Biofuels have come to the market for several reasons. Ethanol was introduced to the gasoline sector, at a performance penalty, to reduce light-vehicle nitrogen oxide (NOx) and sulfur oxide (SOx) emissions and enable clean air. As petroleum prices climbed, various additional forms of renewable source biofuel became an economic and security option and a fossil fuel substitute. Today, especially for aviation fuel candidates, the driving force is the GHG footprint. Biofuels present the opportunity for lower GHG emissions footprints because the biomass feedstocks absorb $CO_2$ for growth during photosynthesis in relatively short time scales and then leave a significant portion of it in the ground when parts of the plant are harvested. This absorption then contributes carbon footprint credits which offset some, if not all, of the $CO_2$ emissions in life cycle calculations. Unfortunately, land use changes such as deforestation, conversion of grassland to agricultural production, or diversion of agricultural production to fuel production, are also part of the life cycle calculation and can potentially overwhelm the gain from $CO_2$ absorption.

The Clean Air Act, Energy Policy Act of 2005, and Energy Independence and Security Act of 2007 (EISA), established, and subsequently modified, a Renewable Fuel Standards (RFS) program that defined renewable fuels and set statutory volume requirements for their required use as transportation fuels each year. The EPA is charged with regulating the program. [14]

The 2005 program (RFS1) was aimed at ethanol-gasoline blending and required a ramp-up from 4 billion gallons in 2006 to 7.5 billion gallons of ethanol by 2012.

EISA 2007 created RFS2 and made several important changes. [1]

**NOTE: This material reflects EPA proposed rules released May 5, 2009. Final RFS2 Rules, effective July 1, 2010 differ significantly.**

- Included diesel and off-road fuels as well as gasoline.
- Defined renewable fuel categories.
- Established GHG "full life-cycle" thresholds, requiring comparison of the emission contributions from each future renewable fuel type to the GHG emission characteristics of the gasoline and diesel in use in 2005…. and set a prescribed reduction from those 2005 levels for each fuel type.
- To prevent excessive land use changes, crops and crop residues used to produce renewable fuel are limited to those grown on land cleared or cultivated before enactment of EISA. (Dec 19, 2007)
- Jet fuel and heating oil are not covered, but renewable fuels sold in those markets count toward the renewable fuel volume mandates.
- Corn-based ethanol (conventional ethanol) production was essentially capped at 15 billion barrels per year by 2015.
- New volume targets, shown in Table 8 below, were established.

The basic definition established in this law is: "Renewable fuels are fuels produced from plant or animal products or wastes, rather than from fossil fuels." [15]

EISA 2007 defined and specified separate (but overlapping) categories of renewable fuels. Each category has a separate statutory volume mandate and an emissions reduction requirement.

- Conventional Biofuel
  - Ethanol that is derived from corn starch.
  - Must meet a 20% lifecycle GHG threshold reduction from facilities that started construction after December 19, 2007 (EISA enactment date)
- Advanced biofuel
  - Essentially fuels produced from anything but corn starch.
  - Must meet a 50% lifecycle GHG threshold reduction.
  - Includes cellulosic ethanol and biomass-based diesel.
  - The schedule for Advanced Biofuel includes the schedule for Cellulosic Biofuels, Biomass-based Diesel and Undifferentiated Biofuels.
- Biomass-based diesel
  - Biodiesel, BTL (biomass-to-liquid) diesel, "renewable diesel" if the fats and oils are not co-processed with petroleum.
  - Must meet a 50% lifecycle GHG threshold reduction.
- Cellulosic biofuel

- Renewable fuel produced from cellulose, hemicellulose, or ligin.
    - Example:  cellulosic ethanol, BTL diesel.
    - Must meet a 60% lifecycle GHG threshold reduction.
- Undifferentiated Advanced Biofuels
    - Renewable fuel other than Conventional Ethanol.
    - Must meet a 50% lifecycle GHG threshold reduction.
    - Includes Cellulosic biofuels, biomass-based diesel and co-processed renewable diesel.

The quantities required by the law in each of these fuel categories is shown in the following Table 8. [16]

**Table 8.  EISA 2007 – RFS2 Schedule for Renewable Fuel Use**

| Calendar Year | Conventional Biofuel | Advanced Biofuel | Cellulosic Biofuel | Biomass-Based Diesel | Undifferentiated Advanced Biofuel | Total Renewable Fuel |
|---|---|---|---|---|---|---|
| 2008 | 9 | | | | | 9 |
| 2009 | 10.5 | 0.6 | | 0.5 | 0.1 | 11.1 |
| 2010 | 12 | 0.95 | 0.1 | 0.65 | 0.2 | 12.95 |
| 2011 | 12.6 | 1.35 | 0.25 | 0.8 | 0.3 | 13.95 |
| 2012 | 13.2 | 2 | 0.5 | 1 | 0.5 | 15.2 |
| 2013 | 13.8 | 2.75 | 1 | | 1.75 | 16.55 |
| 2014 | 14.4 | 3.75 | 1.75 | | 2 | 18.15 |
| 2015 | 15 | 5.5 | 3 | | 2.5 | 20.5 |
| 2016 | 15 | 7.25 | 4.25 | | 3 | 22.25 |
| 2017 | 15 | 9 | 5.5 | | 3.5 | 24 |
| 2018 | 15 | 11 | 7 | | 4 | 26 |
| 2019 | 15 | 13 | 8.5 | 4.5 | 4.5 | 28 |
| 2020 | 15 | 15 | 10.5 | | 4.5 | 30 |
| 2021 | 15 | 18 | 13.5 | | 4.5 | 33 |
| 2022 | 15 | 21 | 16 | | 5 | 36 |

Source:  American Coalition for Ethanol

The Ethanol industry has been encouraged by a number of incentives, including:

- Volumetric Ethanol Tax Credit – the “Blenders Credit”
    - Created in 2004 as part of the American Jobs Creation Act.
    - Originally $.51 per gallon; reduced to $.45 per gal Jan 1, 2009.
- Small Ethanol Producer Tax Credit – IRS Code Section 40
    - If producing less than 60 million gals / year; $.10 per gal; max $1.5 million.
- E85 Infrastructure Tax Credit
    - Energy Policy Act of 2005.
    - 30% federal income tax credit; $30,000 max.

  - Establishing refueling station for clean fuels (85% of total volume) to include ethanol, natural gas, LNG, hydrogen, and diesel (at least 20% biodiesel).
- Depreciation Allowance
  - Tax Relief and Health Care Act of 2006.
  - Allows deprecation deduction of 50% of the adjusted basis of a new ethanol plant in the year it's put in service.
- A large and varied set of U.S. Department of Agriculture Grant and Loan programs.

#### 3.1.7.2 Ethanol Lessons Learned

- The U.S. produced 8.9 billion gallons of ethanol in 2008, which was approximately 5% of the total light-duty road transportation fuel used. According to data compiled by DOE's Energy Information Agency, the corn-based ethanol industry received $3 billion in tax credits in 2007. U.S. Department of Agriculture (USDA) estimates that about one third of the total U.S. corn crop and 10% of arable U.S. land will be used to produce ethanol during the 2008-2009 corn marketing year and could increase to 35 % by 2018. Corn prices have more than tripled from $1.74 a bushel in 2005 to $5.37. Soybean futures recently closed at $14.24 a bushel, nearly tripling in the last thirteen months. [17]
- The Congressional Research Service concludes that "this is a lot of cost and unintended consequence for a small fraction of improvement". [18 (12)]
- Energy efficiency has haunted the ethanol program. Unlike Brazilian sugar cane-based ethanol that has a 7-8 to 1 energy balance (amount of energy obtained compared to the amount of energy required to produce it), corn-based production has struggled to maintain a 1.25 to 1 balance. A 2007 National Renewable Energy Laboratory of DOE (NREL) study reported that results vary widely, but most reports using similar assumptions show a minimal positive energy balance, i.e. that a gallon of ethanol delivers slightly more energy than it takes to produce it. There are many factors and problems and any of them can cause the energy balance to swing negative. [18 (15)]
- The EISA 2007 RFS2 requirements contain a 20% life cycle GHG threshold reduction (compared to the 2005 gasoline and diesel life cycle GHG footprint). This is not an automatic situation for ethanol and is dependent on system boundaries and many factors, including the source of process energy and land use accounting procedures. Some Life Cycle Assessment (LCA) methodologies would keep ethanol from meeting the standard. [18 (3)]
- Market price sensitivity. The ethanol industry did well during the 2005-2006 high oil prices, but in late 2008 ethanol prices exceeded gasoline prices. Several major producers, including White Energy, VeraSun Energy Corp, and Panda Ethanol declared bankruptcy. [19] Operating on a thin margin creates significant vulnerability to intentional or unintentional variations in crude prices.

The prepublication synopsis of an about to be released (2009) National Academy of Sciences study, *Liquid Transportation Fuels from Coal and Biomass Technology Status, Costs and Environmental Impacts*, [20] provides another perspective.

“Cellulosic biomass – obtained from dedicated fuel crops, agricultural and forestry residues, and municipal wastes – could potentially be sustainably produced at about 400 million dry tons per year with today’s technology and agricultural practices and with minimal adverse impacts on U.S. food and fiber production or on the environment. A key assumption underlying this estimate is that dedicated fuel crops will be grown on idle agricultural land. By 2020, the amount of sustainably produced biomass could reach 550 million dry tons per year.”

“If all necessary conversion and distribution infrastructure is in place …. and assuming that the rate of building cellulosic plants exceeds that of corn-grain-ethanol plants (which grew by 25 percent per year over a six year period) by 100 percent, alternative fuels could be added to the U.S. fuel portfolio at a rate of up to 0.5 million barrels of gasoline equivalent per day by 2020. By 2035, up to 1.7 million barrels per day could be produced in this manner, leading to about a 20 percent reduction in oil used for light-duty transportation at current consumption levels (9 million barrels per day).”

“Attaining supplies of 1.7 million barrels of biofuels per day … will require the permitting and construction of tens to hundreds of conversion plants and associated fuel transportation and delivery infrastructure. It will take more than a decade for these alternative fuels to penetrate the U.S. market. In addition, investments in alternative fuels have to be protected against crude-oil price fluctuations.”

Table 9 shows the National Academy of Sciences estimate of comparative fuel prices.

**Table 9. Estimated Costs of Fuel Products With and Without a $CO_2$ Equivalent Price**

| Fuel Product | Cost Without $CO_2$ Equivalent Price ($/bbl of Gasoline Equivalent) | Cost With $CO_2$ Equivalent Price of $50/ton ($/bbl Gasoline Equivalent) [$ Per Gallon] |
|---|---|---|
| Gasoline at Crude-Oil Price of $60/bbl | 75 | 95 [2.26] |
| Gasoline at Crude-Oil Price of $100/bbl | 115 | 135 [3.21] |
| Cellulosic Ethanol | 115 | 105 [2.50] |
| Biomass-to-Liquid Fuels Without Carbon Capture and Storage | 140 | 130 [3.10] |
| Biomass-to-Liquid Fuels With Carbon Capture and Storage | 150 | 115 [3.10] |
| Coal-to-Liquid Fuels Without Carbon Capture and Storage | 65 | 110 [2.62] |
| Coal-to-Liquid Fuels With Carbon Capture and Storage | 70 | 90 [2.14] |
| Coal-and-Biomass-to-Liquid Fuels Without Carbon Capture and Storage | 95 | 120 [2.86] |
| Coal-and-Biomass-to-Liquid Fuels With Carbon Capture and Storage | 110 | 100 [2.38] |

[a] Numbers are rounded to the nearest $5.

### 3.1.7.3 Aviation Biofuel Perspective

Standard biodiesel and ethanol, the main biofuels used in road transportation, have set the stage but are not directly suitable for most aircraft. There are several broad types of research looking at aviation biofuel candidates.

The International Civil Aviation Organization (ICAO) represents a significant fuel consumption group that has suffered the same cost and security challenges as the U.S. Air Force. The ICAO has created a special research and analysis function, the Group on International Aviation and Climate Change, which held their fourth meeting in Montreal in May 2009. An Appendix to their published report, *Carbon Neutral Aviation Growth through Alternative Fuels,* [21] contains some interesting observations. As this title indicates, the analysis quickly turns to the evaluation of biofuel sources because of the increase in aviation fuel use and the pressures to reduce GHG emissions that are expected.

The following two maps show the land requirements for different biofuels to enable the supply of the 2050 estimated quantities of U.S. or total world jet fuel with a 50/50 blend of biofuel and conventional jet fuel – the dashed circles – or 100 percent biofuel – the solid circles. These representations are drawn on Gall-Peters projections so that areas of equal size are equally sized on the maps.

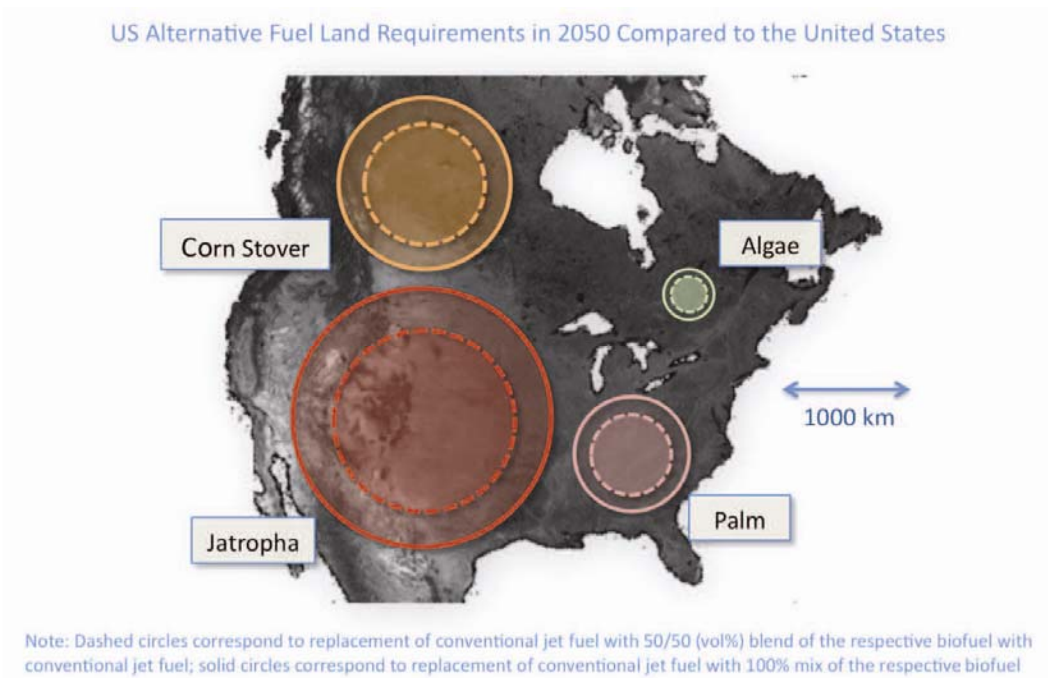



**Figure 20. Land Area Requirements for Different U.S. Jet Biofuels**

In the short term, palm oil appears to many experts as the most likely feedstock for aviation biofuels. Neste Oil is building the world's biggest palm oil biofuel refinery in Singapore which they state can be converted to produce jet fuel. Neste is currently the only company that produces biodiesel from hydro-treated plant oil at a commercial scale. [22] Palm oil has a well established product base in cooking and especially in Europe as a heat and power provider. Yet, the palm oil required to replace half of U.S. jet fuel with palm hydro-treated renewable jet (HRJ) would be more than three times current world production. "Because palm oil requires fertile

land in tropical regions, its use as a biofuel would likely lead to land use changes with large GHG emission penalties." [21]

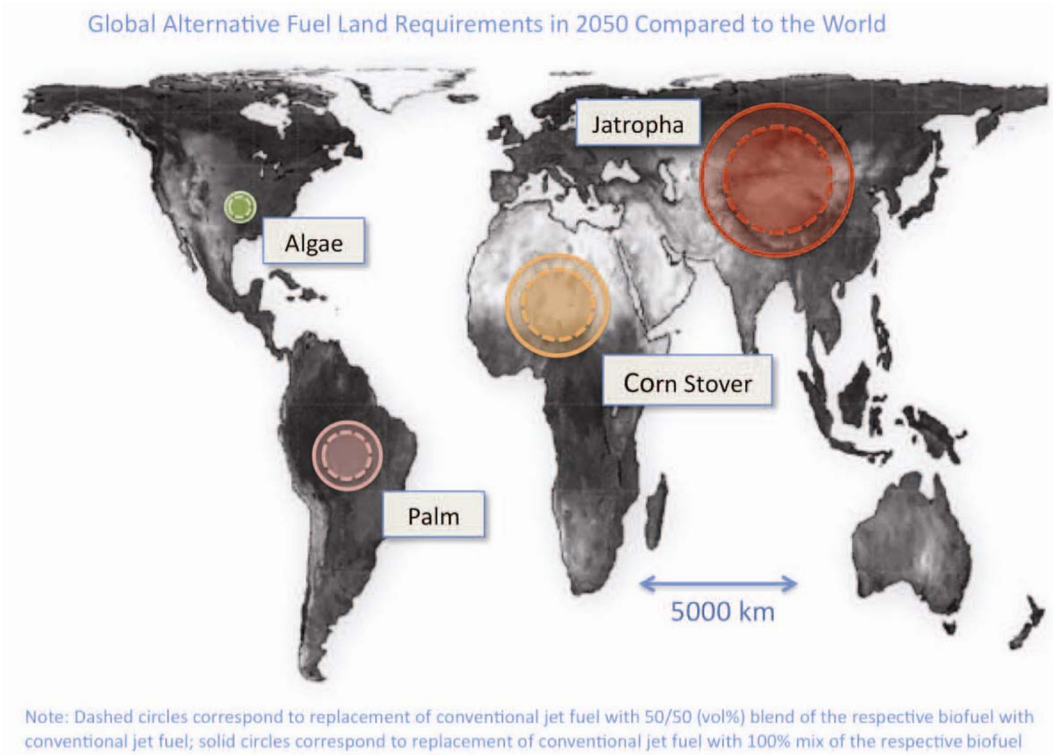



**Figure 21. Land Area Requirements for Different Global Jet Biofuels**

Because jatropha can be grown on marginal land there may be reasons for its use. "The most promising feedstock-to-fuel pathway thus far examined by the research team is algal HRJ." The algae area shown on the world map is slightly larger than the nation of France – the jatropha area the size of Russia. These estimates also assume that other industries, like electricity, would continue to use fossil fuels. Soybean HRJ was not included on these charts because it would not fit; the required land area would be 1.6 times that of Jatropha. [21]

One of the major report conclusions was:

> "*The most significant challenge is not in developing viable alternative fuels that could reduce aviation's GHG emissions—the technology exists; rather the challenge lies in development and commercialization of next generation feedstocks such as algae, jatropha, and halophytes. Although the economics of production need to be proven, algal feedstocks may be able to produce sufficient jet fuel to replace jet fuel in 2050 for U.S. aviation on a landmass comparable to 9% of U.S. cropland with a 50% reduction in GHG emissions compared to a business as usual scenario. This combined with operational and technological advances, should be sufficient to reduce 2050 U.S. aviation emissions below those of today.*"

Figure 22 summarizes fuels that are possible from various biomass processes. The most promising "drop-in" candidates are circled.

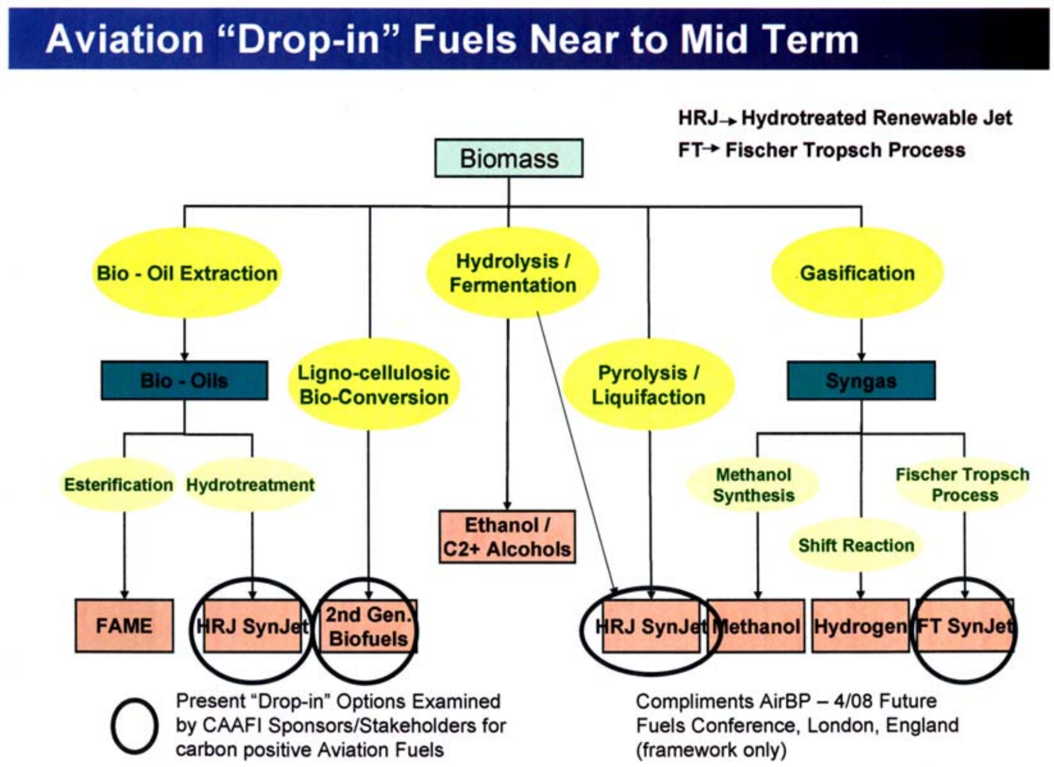



**Figure 22. Aviation "Drop-In" Fuels Near to Mid Term**

## 3.2 Technology and Process Drivers

### 3.2.1 Carbon Control

The release of carbon dioxide into the atmosphere has become a major international concern. The U.S. annually releases approximately 6 (22 %) of the world's 30 billion metric tons (Gtons) of man-made $CO_2$.[23 (4)] Almost 90% of these emissions are associated with the production and use of petroleum, coal, and natural gas, in order of decreasing contribution. Currently, over 77% of U.S. electric generating capacity is based on fossil fuels. Coal plants alone meet nearly 50% of this electricity demand and in turn contribute 82 % of electricity generation related $CO_2$ emissions.[24] The 500 most prolific U.S. stationary point source $CO_2$ emitters, 390 of which are coal-fired power plants, emit 2.38 Gtons per year. This translates to an average of 4.7 million tons per year for an electric generating plant – in contrast to the 10-12 million tons per year a typical 50,000 bpd CTL plant would produce.

> *While the U.S. share of global emissions will decline as energy use in the developing world continues to grow rapidly over the next few decades, the EIA projects that the amount of U.S. emissions could rise by about one-third by 2030 with the emissions from transportation maintaining roughly one-third of this larger number.*[25]

The transportation sector is the largest single area of oil consumption (15 million barrels per day or 68% of total petroleum consumption) and thus this sector is responsible for 34% of all $CO_2$ emissions in the United States, making it the largest end-use sector emitter at 2,014 million metric tons of $CO_2$ in 2007.[26]

"NETL, in November of 2008, released a detailed study that found the WTT (well-to-tank) GHG emissions profile of petroleum-derived diesel fuel to be 18.3 Kg$CO_2$E/million BTU (LHV) of diesel fuel dispensed based on the average U.S. transportation fuel sold or distributed in 2005." "When the WTW (Well-to-Wheels) life cycle emissions are considered and vehicle operation is included in the emissions profile, the total life cycle GHG emissions are 95.0 Kg$CO_2$E/mmBtu (LHV) of fuel consumed (or 7.3 kilograms per gallon of diesel fuel consumed). [26 (23)] Note: The 95 Kg /mmBTU or 7.3 Kg/gallon are broken down: raw material acquisition-7%, raw material transport-1%, liquid fuel production (refinery)-10%, production transport & distribution-1%, vehicle operation-81%. [26 (24)]

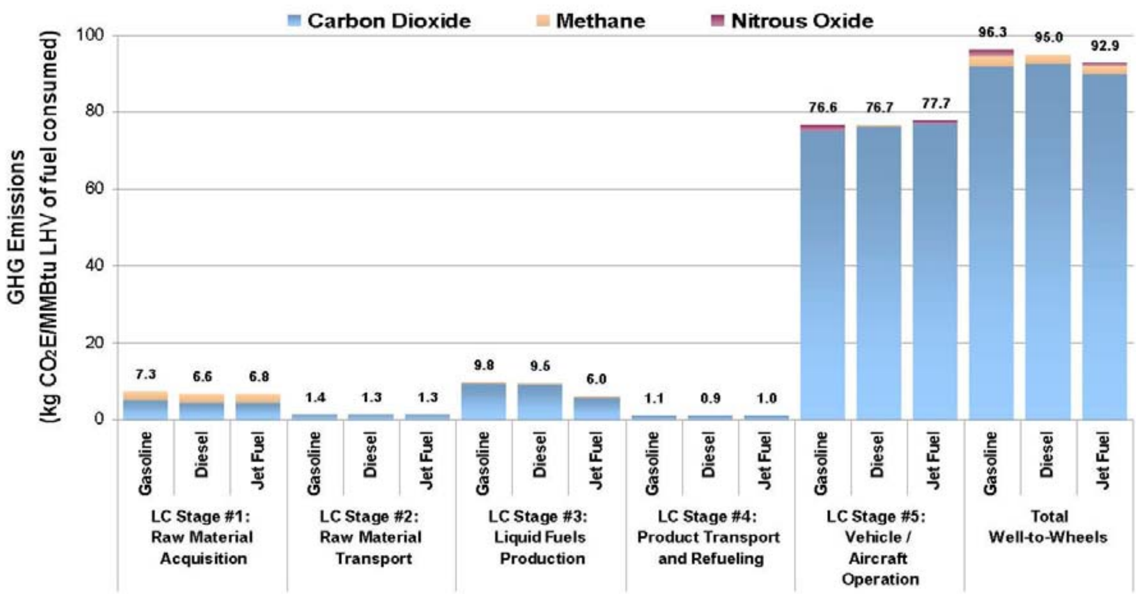
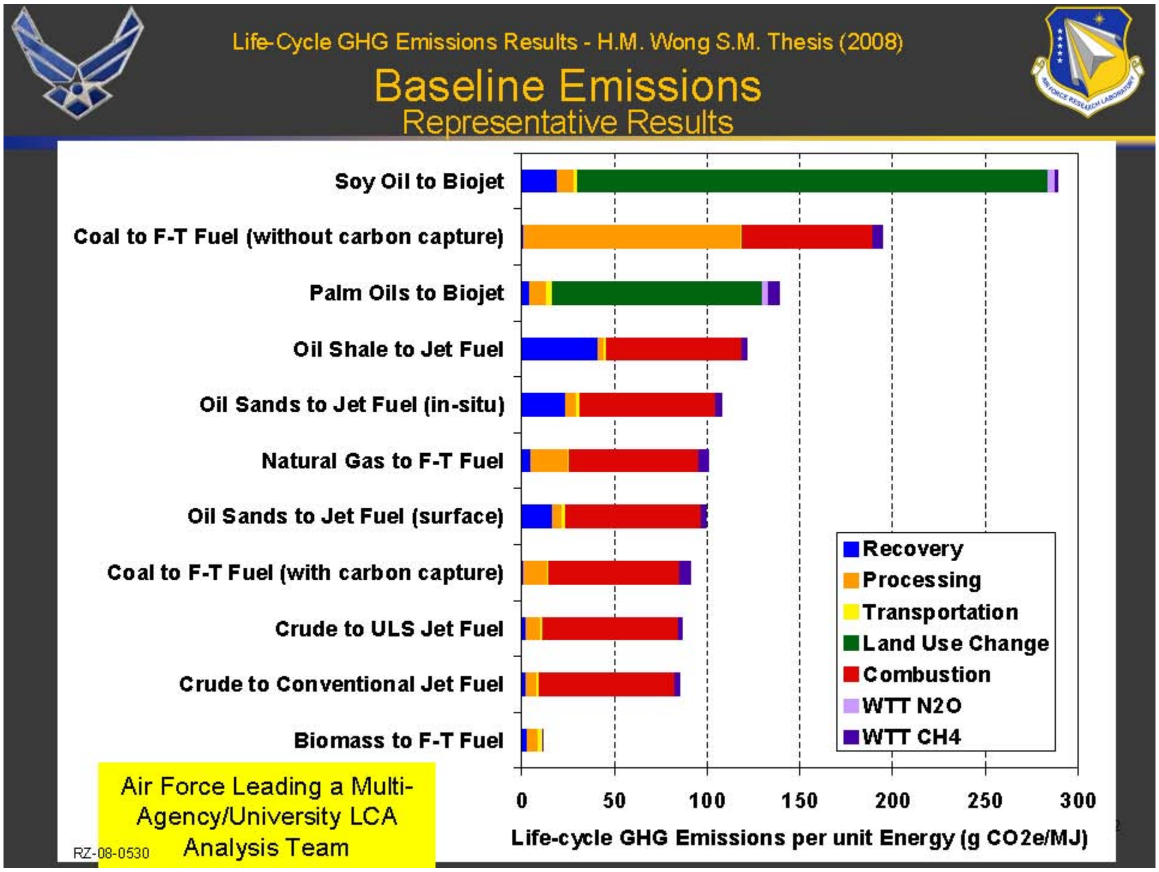



**Figure 23. Life Cycle GHG Emissions for Conventional Transportation Fuels**

Comparing these numbers with CTL, the NETL study found that a CTL process with carbon capture and sequestration (CCS) of 91% of produced $CO_2$, results in a GHG emissions level of 90.2 Kg$CO_2$/mmBtu or 5% less than the petroleum baseline. [26 (25)]

A November USAF AFRL presentation contains a comparison of various fuels ability to meet emission standards. [27]




AFRL Presentation, November 2008

**Figure 24. Baseline Emissions**

The environmental community in the U.S. has mounted an aggressive campaign against coal. All coal projects and their related permitting process are now being legally challenged. Although badly needed to improve efficiency and replace outdated units, ninety two coal fired electrical generation projects have been blocked since 2002. The Energy Independence and Security Act of 2007 mandates in Section 526 that no federal agency can purchase a synthetic fuel with a carbon footprint greater than its petroleum equivalent. Thus, it is clear that any coal related project must have a comprehensive carbon control component. The Waxman-Markey Climate Bill, commonly called the American Clean Energy and Security Act of 2009 introduced in early 2009, contains, in Section 121, a Low-Carbon Fuel Standard provision that requires consideration of a fuel's total life-cycle carbon footprint. This would, in effect, extend the Section 526 federal agency fuel purchase restriction to all private markets nationwide. It would be strongly prejudiced against any heavy crude and as initially written could block imports from Canada and Mexico which account for 40% of the current U.S. supply. [28 (14)]

#### 3.2.1.1 Carbon Control Issues

#### 3.2.1.2 Policy

The 2007 MIT study, The Future of Coal, [29] made a detailed study of the implications and costs associated with adding carbon control to a coal-based enterprise. The findings highlight the significance of national policy, the regulation and control process, and the taxing mechanism. Given that none of these elements has been defined or legislated, the study strongly recommends that the energy industry and new technology developers should not take action to commercially incorporate or implement carbon capture and control…. if you don't know the rules, do not play the game! The design elements, their costs, and the costs to change or retrofit are very significant and very rule dependent.

Volumes of material have been written on the cap-and-trade and direct taxation concepts. Most control systems are complex, a significant constraint to industry, and have been demonstrated in Europe and Asia to be susceptible to mismanagement and corruption. The system proposed by the Waxman-Markey bill has drawn criticism from many government and industry perspectives. Some fear that energy-intensive products like steel, glass, and cement would be driven out. A senior analyst observed that a carbon credits market could take on the same characteristics as the mortgage derivatives market if investors were allowed to securitize emissions credits without strong regulatory oversight and enforcement. Indiana Governor Mitch Daniels, in a May 15, 2009 Wall Street journal article said, "This bill would impose enormous taxes and restrictions ….and would more than double electricity bills in Indiana."

The April 17, 2009 HIS Cambridge Energy Research Associates (IHS CERA) report Grounding the Positive Charge: Finding the Cost of Reducing $CO_2$ Emissions by Increasing U.S. Electric Efficiency [30] states:

> *"Putting a price on $CO_2$ emissions to stabilize or reduce future $CO_2$ emissions will involve annual charges of tens of billions of dollars. Distributing this cost burden fairly is challenging because these costs are distributed unevenly across income levels and geographies."*

The many different approaches suggested in recent proposals seem to validate the wisdom of the 2007 MIT recommendations.

#### 3.2.1.3 Injection Technology

It is widely accepted that carbon dioxide capture and sequestration (CCS) must accompany any coal-based facility and is conceptually feasible. However, the injection or pour rate may be a technical issue. A 40-50,000 bpd CTL plant could generate 10-17 million tons of $CO_2$ per year or approximately a million tons per month. The World's limited commercial injection experience is comprised of two data points. The Statoil oil company in Norway has injected one million tons per year into a sandstone aquifer 3,300 feet below the North Sea Sleipner oil field since 1997. In the U.S., the Great Plains SNG Plant in North Dakota has pumped two million tons per year, 205 miles to the Weyburn oilfield in Saskatchewan since 2000 for Enhanced Oil Recovery. [31 (26)] None of the CTL or GTL plants being developed in China or the Middle East has, to this point, included carbon capture and sequestration. There is concern that, dependent on yet to be accomplished testing, a CTL plant could require multiple injection points and the resultant pour area could cover more than 200 square miles.

It has been repeatedly shown that the complex nature of CTL plant design and development is subject to scale-up problems.  This significant scale increase could hold unforeseen problems and is one of the reasons that, in spite of positive theoretical indications, many experts have made the demonstration of several large sequestration operations a high priority.  Such a commercial scale integration and demonstration was the purpose of the “original” multi-nation, industry-government Mattoon Illinois DOE FutureGen project started in 2003 and scheduled for operation in 2012.  It is also the reason for the strong objections raised by its cancelation in January 2008. The restructured FutureGen program is scheduled to begin test injections at multiple sites by the end of 2015, seeking to answer the same questions. [32]  Apparent reinstatement of the original Mattoon program puts the investigation back on track but on a delayed schedule.

### 3.2.1.4 Enhanced Oil Recovery

The U.S. had a large oil resource base, on the order of 596 billion barrels originally in-place. About one-third of this oil resource base, 196 billion barrels has been recovered or placed into proved reserves with existing primary and secondary oil recovery technologies.  This leaves behind a massive target of 400 billion barrels of “technically stranded” oil.

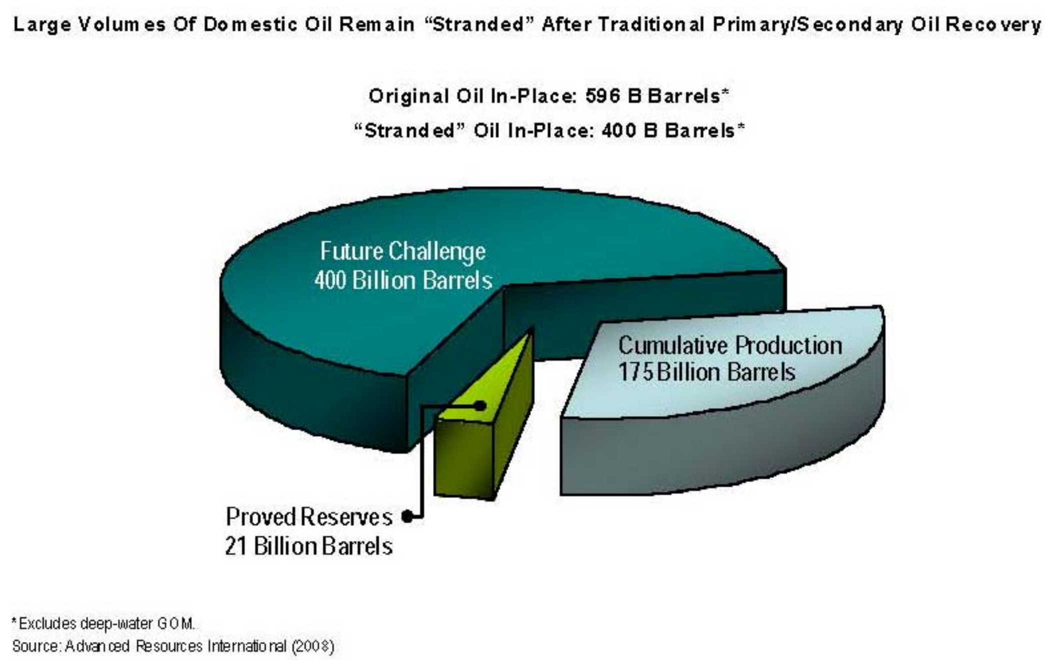



**Figure 25.  The Domestic Oil Resource Base**

The 2008 NETL study, Storing $CO_2$ with Enhanced Oil Recovery (EOR), [33] determined that approximately 319 billion barrels of the stranded oil in 1,111 different reservoirs, is amenable to $CO_2$-EOR and that the recovery of on the order of 40 billion barrels is economically viable at a $50 per barrel oil price with current EOR technology.

The EOR process has been used in the U.S. for more than thirty years but has grown from a few sites in the 1970s to more than a hundred sites using 30-40 million tons of $CO_2$ per year, today. The initial or primary recovery yields from 20-40% of the oil a well contains.  Pumping high pressure $CO_2$ into the well raises the total another 15-25%.  Current yield from EOR is estimated to be 250,000 bpd – more than 10% of daily U.S. production.  RAND, Producing Liquid Fuels

from Coal: Prospects and Policy Issues, [34] estimates that this could grow to between one and two million barrels per day. (33)

Figure 26 shows the growth and geographic source of $CO_2$-EOR production to date.

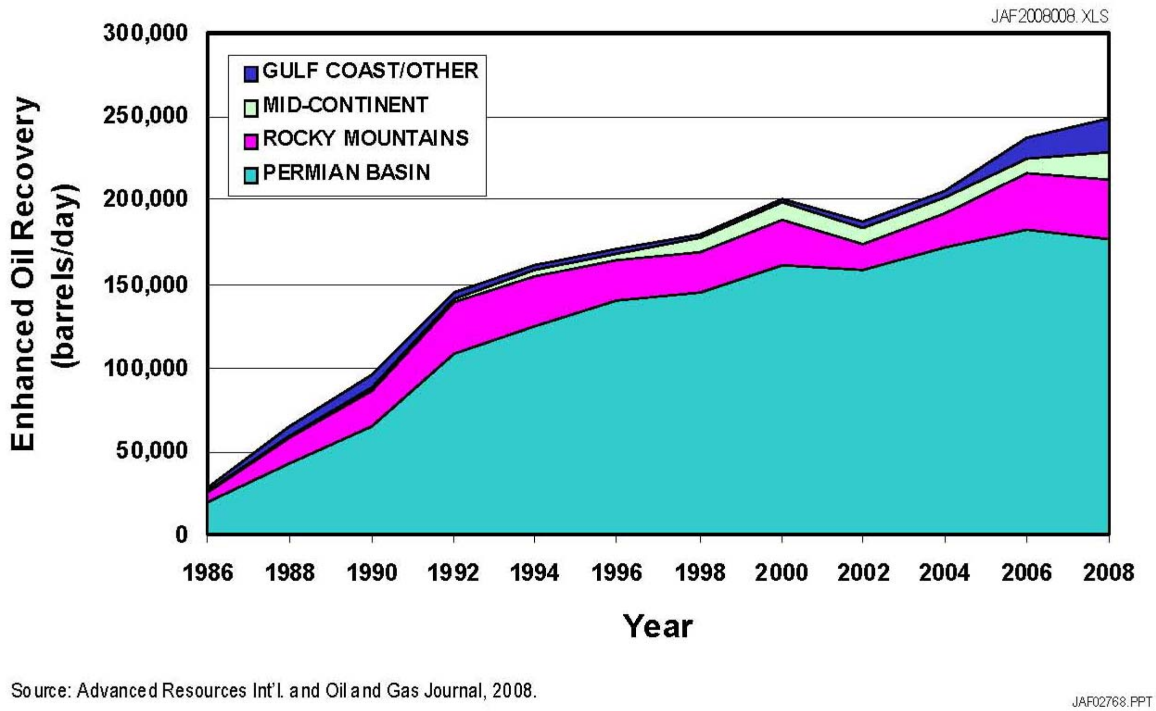



**Figure 26. Growth of $CO_2$-EOR Production in the U.S.**

Denbury Resources is one of the major EOR producers. They have several hundred miles of dedicated pipeline feeding many Gulf Coast oil fields and are currently constructing a 300 mile 24 inch diameter pipeline from Louisiana to Houston. Denbury has several $CO_2$ supply contracts, in the first quarter of 2009 signed four additional contracts with gasification projects under development and has several more under consideration. Denbury operating expenses were \$20.48 per barrel in the first quarter of 2009. [35] (14)

Figure 27 shows the current U.S. $CO_2$ pipelines.

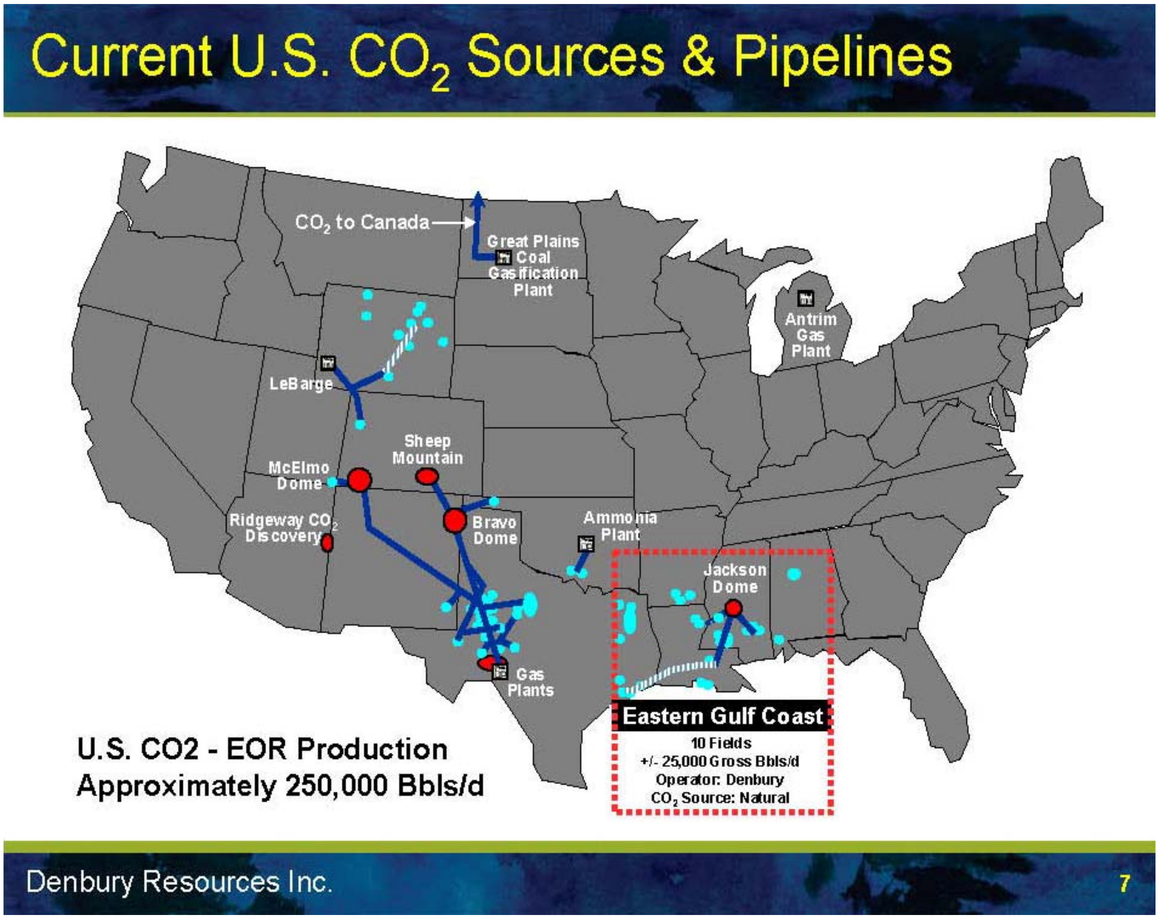



**Figure 27. Current U.S. $CO_2$ Sources and Pipelines**

Despite biased information to the contrary, the vast majority of $CO_2$ used for EOR has so far stayed in the well and thus achieves a stable long term sequestration objective.

### 3.2.1.5 Geologic Sequestration

Geologic sequestration is defined as the placement of $CO_2$ into an underground repository in such a way that it will remain permanently stored. DOE is investigating five types of underground formations for geologic sequestration, each with different challenges and opportunities for $CO_2$ sequestration.

- Mature oil and natural gas reservoirs
- Deep unmineable coal seams
- Deep saline formations
- Oil and gas rich organic shales
- Basalt formations

DOE's Carbon Sequestration program, launched in 1997, is developing a set of technologies to be ready by 2012 and have the overall goal of achieving 90 percent $CO_2$ capture with 99 percent storage permanence at less than a 10 percent increase in the cost of energy services.[23 (5)] NETL plans to be ready for large-scale testing of the technologies by 2018.

### 3.2.2 Water Use

The supply and use of water is another environmental issue of growing concern. The generation of electricity in the U.S. accounts for 39 percent of all freshwater withdrawals in the country, making it second only to agriculture in freshwater use. Table 10 shows water consumption for various electricity generation technologies.

**Table 10. Water Consumption by Generation Technology**

| Technology | Gallons/kwhr |
|---|---|
| Coal | 0.49 |
| Natural Gas Combined Cycle | 0.25 |
| Nuclear | 0.62 |
| IGCC | 0.55 |
| Wind | 0.001 |
| Solar Thermal | 0.79 |
| Photovoltaic | 0.03 |

[The Future of Electricity, School of Public and Environmental Affairs, Indiana University, May 2009]

Water use is important in the consideration of synthetic fuel production because of the quantities involved. The traditional Fischer Tropsch coal-to-liquid fuel process requires on the order of five gallons of water per gallon of fuel; ethanol uses 3-6 gallons per gallon.

A May 2009 *American Meteorological Society* study reports a significant decrease in flow in a third of the world's big rivers and cites several interesting examples. "Water flowing to the Pacific Ocean, for instance, is down about 6%, which is about equal to shutting off the Mississippi River." "Without significant cuts to demand from the river, the U.S. Bureau of Reclamation will be unable to deliver the amounts of water that states in the Lower Colorado River Basin have been allocated." [36]

A recent *New York Times* article reports that the Bureau of Land Management is studying the impact of the estimated 63 large-scale solar projects proposed for BLM lands in Nevada and the surrounding region. "In arid settings, the increased water demand from concentrating solar systems employing water-cooled technology could strain limited water resources." [37]

*Business Week*, April 23, 2009, "predicts that water prices across the U.S. will double or triple over the next few years".

*The Wall Street Journal*, March 19, 2009, reports that "oil companies have gained control over billions of gallons of water from Western rivers in preparation for future efforts to extract oil from shale deposits." Public records show that energy companies are entitled to divert more than 6.5 billion gallons of water a day and hold rights to store 1.7 million acre feet of water which would be enough to supply Denver for six years.

### 3.2.3 Hydrogen

The use of hydrogen to reduce vehicle emissions has received a large amount of attention and government (DOE) funding over the last decade. It certainly results in cleaner but usually not a cheaper fuel or more efficient energy conversion. It is important to remember that hydrogen is a carrier of energy but not a source of energy. Hydrogen must be created by another energy source, like nuclear or coal-produced power or heat, and suffers the normal conversion losses.

Hydrogen works well in fuel cells which have many useful applications. When coupled with electric motors, which provide the most efficient means of vehicle propulsion, they were hoped to provide an attractive replacement for internal combustion engines. However, very high unit cost, the fact that the water by-product freezes in most parts of the U.S., and the lack of a hydrogen production and distribution infrastructure, have posed a serious impediment.

The DOE Secretary, Steven Chu announced on May 7, 2009 that "cars powered by hydrogen fuel cells will not be practical over the next 10-20 years and the government will cut off funds for the vehicles development to focus on projects that will bear fruit more quickly." [38]

## 3.3 Mid-Term – 5-15 Years

The current technologies that ten years ago were thought to be the wide road to fuel security and affordability have hit a series of roadblocks. Recent synthetic fuel plant designs have been characterized by large scale, low conversion efficiency, excessive carbon by-product, and significant water use. These items have been major impediments to their financing and construction. The risks and low efficiencies associated with these multi-billion dollar developments just have not been saleable in the presence of unproven technical aspects and a difficult funding environment.

Coal seems to be on hold for a decade or more. Carbon control technologies and policies must mature enough to make coal environmentally acceptable. Government and private research is looking for ways to improve the traditional processes but is also developing alternatives.

### 3.3.1 Oil and Clean Coal

In typical American problem solving fashion, a variety of small innovative technology companies have emerged. Several seem to have developed designs that achieve much higher efficiencies with minimal water use and greatly reduced $CO_2$ production. These systems attack known problems and target tailored niche market applications. They may be the path to the alternative energy and fuel future.

The quantities and percentages of energy that oil and coal contribute are enormous and often difficult to comprehend. A British author, David J.C. MacKay in *Sustainable Energy*, uses some analogies that help grasp the quantities.

> *Driving an average car 50 km per day uses 40 kWh per day. Covering the windiest 10% of Britain with onshore windfarms would yield 20 kWh per day per person; covering every south-facing roof with solar water-heating panels would capture 13 kWh per day per person; and wave machines over 500km of coastline would provide 4 kWh per day per person.*

Secretary of Interior Ken Salazar recently proposed in a March 11, 2009 Press Release and subsequent New Jersey speech "that windmills off the U.S. East coast could generate enough electricity – 1 million megawatts - to replace most, if not all, the nation's coal-fired power

plants." [39] It would take, using today's largest wind turbines operating at 50% efficiency (normal is 30%), more than 40,000 turbines. It's been calculated that if you used the entire East coast it would take many rows of wind turbines to accommodate that number. Possible – maybe; probable – not really.

Most energy experts see cleaned-up fossil fuels as a major component for the foreseeable future.

The current situation is constrained not by fuel source options but by how we choose to use them. Conceptually, U.S. coal reserves, comprising 27% of the known world reserves, a large quantity of tar sands, or oil shale that contains more than 100 times more crude oil than has been produced in the U.S. until now, contain more than enough potential energy to satisfy our needs. The difficulty is that the processes we have for using coal or extracting oil shale crude to make fuel have several difficult challenges.

- The coal gasification and F-T processes are relatively inefficient.
- Large quantities of water are required.
- Optimal operating cost requires a very large and very expensive plant scale.
- The quest for improvement has resulted in modified technologies and increasing first article production risk until the improvements can be matured.
- The significant quantity of carbon dioxide produced as a by-product is not consistent with current climate concerns.

It's not clear that the alternate fuel sources - oil shale, tar sands, ethanol, bio or algae - often suggested, offer an easier path. They have many of the same problems and some different problems of equal magnitude.

Thus, the improvements we need to realize involve "elegant" solutions to replace the "brute force" methods now frustrating us. We need new ways to use, extract or grow, process, and distribute the energy.

### 3.3.2 Small Scale Energy and Fuel Producing Systems

A few examples:

**<u>Gasification</u>**

Diversified Energy based in Arizona, has developed a series of very promising alternative and renewable energy technologies. An advanced gasification technique with feedstock flexibility is focused at many possible applications, including low cost co-located industrial syngas supply and mobile liquid fuel production. A biofuels conversion process produces high quality transportation fuels. And, the company has also developed an algal biomass cultivation system with breakthroughs in both scalability and economy. Diversified has received several grants and contracts from DOE, DOD, and private industry. [40]

InEnTec's plasma-enhanced melter (PEM) technology produces an ultra-pure syngas that can be converted into H2, ethanol, methanol, and diesel from almost any feedstock. The first commercial chemical-waste recycling plant in North America will be at Dow Corning's Midland, MI process facility. Based on a ten-year contract, start-up is expected in late 2009. Another example, a Sierra Biofuels plant near Reno will use PEM to convert household garbage to transportation fuel. [41]

**Coal**

Velocys, a Battelle Institute spin-off has developed a novel microchannel-hydropocessing technology. This high conversion efficiency F-T approach enables distributed small scale units and also is able to effectively process heavy crude. The company has received several supportive grants and was recently selected for a $5 million Third Frontier Research Commercialization Program grant by the State of Ohio. [42]

Carbon Fuel, a Colorado company, uses hydrodisproportionation to refine coal using common petroleum refinery process equipment. [43] Gasoline, diesel, jet fuel or petrochemicals are produced with a 85% energy conversion efficiency. No water is required and very little $CO_2$ is produced. The per gallon capital cost is less than 50% of a typical F-T plant. An 18 ton per day coal feedstock development plant has demonstrated the process and led the way for a 500 ton per day pilot commercial facility.

The University of Texas at Arlington recently announced they have succeeded in producing Texas intermediate-quality crude from low cost, low quality, widely available lignite coal. The process is chemical rather than combustion in nature and thus does not emit carbon dioxide. It yields hydrocarbon chains between C23 and C33 which lend themselves to producing desirable petroleum products. Microrefineries fitting in a 20 foot cube and costing approximately $5 million each could produce 500 to 1,000 barrels of crude per day at under $35 per barrel. Associate Dean of Engineering and Research, Rick Billo is looking ahead to a demonstration industrial size refinery and a set of ten “ganged” micorefineries producing 10,000 barrels per day. UTA’s methodology was based on previous work at the University of West Virginia, which holds patents on converting higher grade bituminous coal with a similar process. The UTA plan is to license the process to industry. New goals for the summer of 2009 are to increase yield and demonstrate that the crude can be further refined into jet fuel. [44]

**Biofuel**

Waste-to-energy (WTE) refers to any waste treatment that creates energy from a waste source. Many technologies including plasma-arc gasification, plasma-torch gasification, pyrolysis and combined pyrolysis-gasification systems have become economically viable. They are growing rapidly and are exploiting the conversion opportunities associated with biomass, municipal solid waste (MSW), and medical, chemical and industrial waste. Nexterra Energy’s biomass-gasification system is providing heat and hot water to residents of an award-winning green development in Victoria, British Columbia. At full capacity it will support 2,500 residents in a carbon-neutral urban environment. [45]

Craig Venter, the American scientist who helped decode the human genome is working with BP to exploit the discovery of bacteria that can turn coal into methane. The bugs were discovered a mile underground and have unique enzymes that can break down coal. This research is in a very early stage and is being viewed with caution, but Ventor’s track record lends credibility.

### 3.3.3 Oil Shale - Tar Sands - Oil Sands

While recognizing that the focus is on synthetic fuel, as pointed out in Section 2, petroleum-based fuel remains a dominate energy source. Considering that fuel security is an issue and thus a primary reason for the Air Force objective to have domestic sources available, some attention to how our domestic oil production could be increased seems appropriate. Beyond deep well drilling, EOR, oil shale and oil sands provide impressive opportunities. [46]

#### 3.3.3.1 Oil Shale

The 800 billion barrels of crude oil estimated to be available in U.S. shale have been a tempting but challenging source. Recovery cost and emissions have been a formidable barrier.

Oil shale must be heated to temperatures between 400 and 500 degrees centigrade to release the kerogen oil and combustible gases. This can be accomplished by mining the shale and heating it in retorts or kilns. In a number of alternative methods, the shale is heated in place, by combustion or slowly with electric or gas heaters for 2-4 years. A variety of research projects since the 1970s investigated methods to improve product quality and reduce production cost. It is expected that, as with Alberta oil sands, methods and efficiency would improve as operations matured.

As with many alternative or unconventional fuels production methods, water use is a factor of interest. It is particularly important because of the sensitive water situation in the Western region where the oil shale is found. Processes developed in the 1970s used as much as 5 barrels of water per barrel of fuel. Recent methods have reduced the need to from 1 to 3 barrels per barrel.

Similar to coal-based processes, the capital cost of oil shale production facilities are highly dependent on shale quality, density, depth, water content, and the process. DOE has estimated that surface retorted fuel-from-oil-shale is competitive with $54 per barrel crude oil and the in situ process with $35 per barrel crude. [47]

Figure 28 was taken from the Task Force on Strategic Unconventional Fuels Volume III report, Resource and Technology Profiles. [48] [(24)] It illustrates why, despite production challenges, this source of heavy crude is considered to be especially well suited for jet fuel and diesel. Compared with normal baseline, Brent and West Texas Intermediate (WTI) crude, which typically yield 8-10 percent jet fuel, products from The Oil Shale Company (Tosco), now part of Conoco-Phillips and Shell's in situ Conversion Process (ICP), show jet fuel yields of as much as 30 percent.

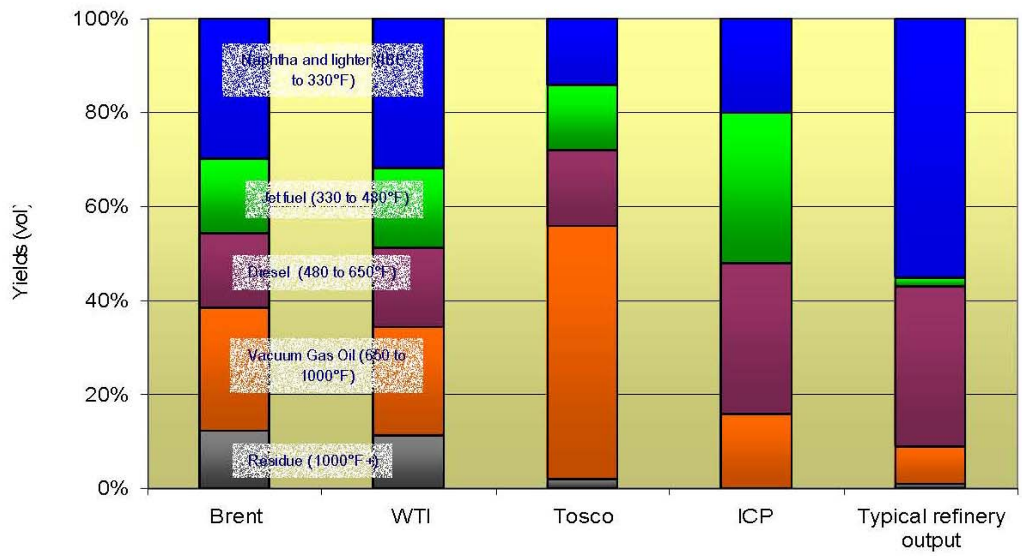



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**Figure 28. Typical Shale Oil Yields**

General Synfuels International (GSI) has announced a new processing system that can recover oil and gas products from oil shale, oil sands, and heavy oil. The in situ process has a very low carbon footprint and high thermal efficiency, can operate at several levels as deep as 3,000 feet, and uses only a small amount of water for cooling. This will be an interesting development to watch. [6 (8)]

In February 2009, Interior Secretary Ken Salazar rescinded the lease offers for research, development, and demonstration projects that could have led to oil-shale works on 1.9 million acres of federal land. [49]

### 3.3.3.2 Tar Sands – Oil Sands

U.S. tar sands – called oil sands in Canada – are a combination of clay, sand, water, and bitumen which is a heavy, black, asphalt-like hydrocarbon. The bitumen can be upgraded to synthetic crude oil and refined to make asphalt, gasoline, jet fuel, and chemicals. It is estimated that U.S. tar sands contain approximately 12-19 billion barrels of recoverable oil. [50]

Canadian oil sands represent recoverable oil reserves – 173 billion barrels - second only to Saudi Arabia. Canada is currently the number one U.S. oil supplier: Canada –(crude and finished products) 2.46 million barrels per day, Saudi Arabia – 1.53 mbd, Mexico -1.3 mbd, Venezuela- 1.19 mbd. The U.S. gets 19% of our crude oil from Canada – half of it comes from oil sands. [51]

Canadian government-private partnerships have done very well with their "oil sands" and continue to expand it, having spent more than $16 billion in capital expenditures in 2007. Technological advance has made possible a more than doubling of production from 2000 to 2008 – to 1.3 million bpd. [Testimony by Dr. Daniel Yergin, HIS CERA, Joint Economic Committee of Congress, May 20, 2009] Significant progress is also being made to reduce the serious environmental challenges – $CO_2$ footprint only 5-15 % larger than "average" crude consumed in the U.S. are associated with current processing. The average amount of steam used today per

unit of output is half of what it was in 2000 and is expected to continue improving. [52] Water and natural gas for processing – 20% of total Canadian use – are targets for efficiency advances.

The fourth major integrated oil sands project in Canada -Long Lake – is located in the Athabasca region of northeast Alberta. Brought on line in 2008 by Nexen, it employs advanced technologies directly aimed at the traditional oil sands production disadvantages of high water and natural gas use. The Steam Assisted Gravity Drainage (SAGD) process injects steam into a horizontal well drilled through the bitumen deposit where it rises through the oil sands and heats the bitumen. The heated bitumen then flows with the condensed steam-water to a parallel horizontal well approximately five meters below, where it is pumped to the surface. The water is separated and recycled back to produce steam. The bitumen is divided – the high density portion normally discarded is gasified to form synthetic fuel which is then used instead of natural gas. The "lighter" portion of the bitumen is upgraded on-site by hydrocracking to "the highest-quality synthetic crude on the market" and thus commands a premium price. The integrated on-site upgrading alleviates the need to use diluents, further reducing production cost. [53]

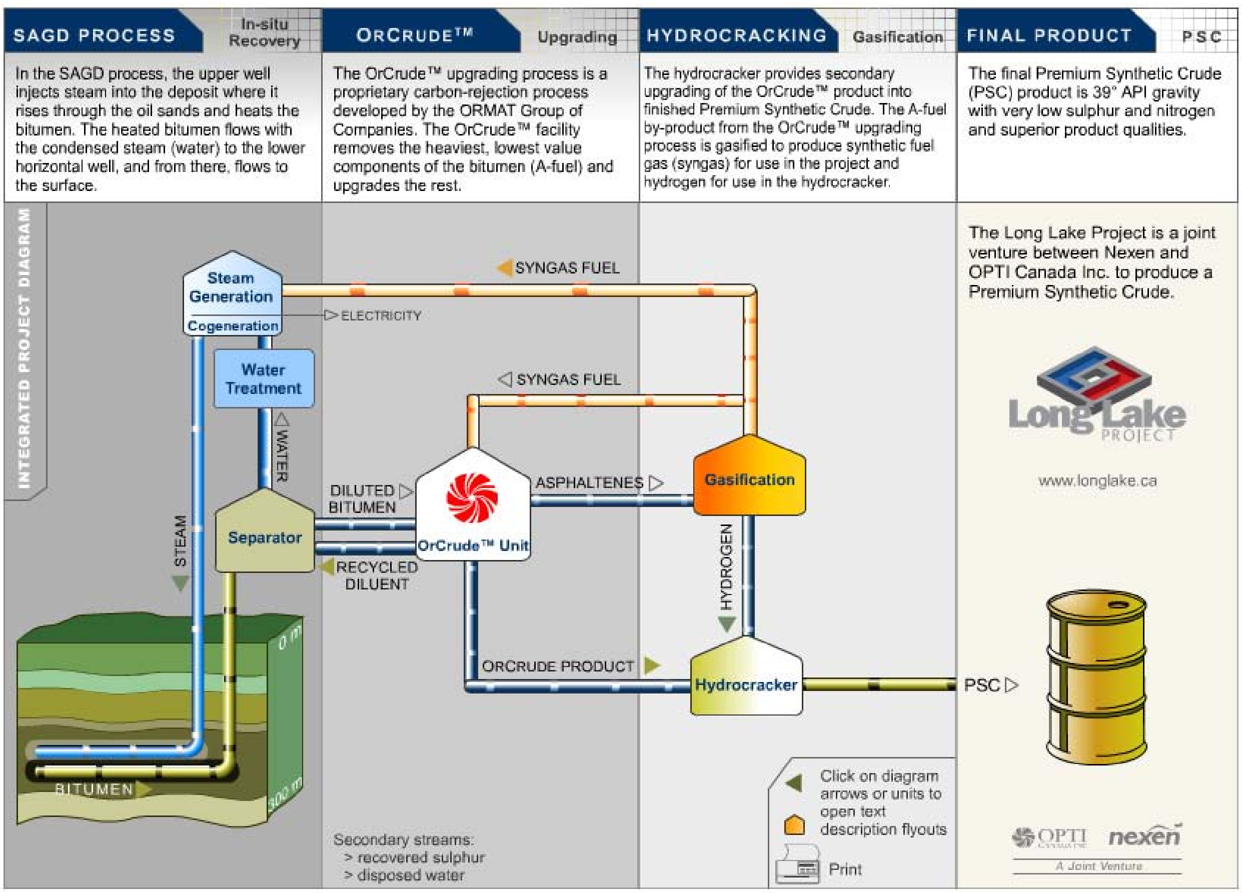


**Figure 29. Long Lake Operation**

(www.Longlake.ca/project)

Continued investment by both government and industry has made significant strides in the development of this unconventional fuel resource. It has been suggested that some of the resultant advanced technologies might be an appropriate model for U.S. oil shale extraction.

Canada's environmental progress and the importance of their contribution to the U.S. energy supply not withstanding, U.S. and Canadian environmental groups are mounting strong opposition. During a two day summit in Washington in late May 2009, they lobbied Congress on pending climate change legislation and issued a statement demanding a moratorium on any further development in Canada and of associated new pipelines and refineries in the U.S. Energy Secretary Steven Chu told Reuters, "It's a complicated issue, because certainly Canada is a close and trusted neighbor and the oil from Canada has all sorts of good things. But there is this environmental concern, so I think we're going to have to work our way through that." [54] Oil from Canada has become a real and current symbol of the energy – climate conflict. The content of any legislation will provide valuable insight into the U.S. energy posture for the coming decade.

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## 4.0 SYNTHETIC FUEL TECHNOLOGIES IN ACTION

This section looks at what has been done and is being planned with synthetic fuel technologies. Details on all current and planned plants are in Appendix D.

### 4.1 Fischer-Tropsch Coal to Liquid Fuel, Sasol – South Africa

The modern Fischer-Tropsch era began in South Africa. In the 1950s, isolated because of apartheid policy, short of petroleum and with an abundance of coal, Sasol (formally the South African Coal, Oil and Gas Company) undertook to update German technology and develop a F-T coal-to-liquid fuel capability. A pilot plant was opened in a new town, Sasolburg, approximately 35 miles south of Johannesburg in 1955. It was converted to GTL operation in 2004 and is still in operation. After years of research, the town of Secunda was built near coal mines 75 miles west of Johannesburg to support two side-by-side nearly identical plants that were brought on-line in 1980 and 1982. Today they produce 150,000 barrels per day of fuel and until very recently were the only significant CTL plants in existence. These plants supply approximately 35% of South Africa's fuel needs and in April 2008, the Secunda fuel was approved for use by commercial airlines.

Another important aspect of the Sasol success story is that all waste by-products were developed into commercial products. There is data to indicate that, today, the chemical products contribute as much revenue as the fuel. Recently, a concept called polygeneration, which embraces a similar multiproduct strategy, has been promoted in the U.S. to make CTL fuel production more potentially profitable.

In October 2007, Sasol placed an order with Japanese manufacturer Hitachi Zosen Mechanical Corporation for a new advanced reactor that will accommodate either coal or natural gas and increase Secunda capacity to 180,000 barrels per day by 2015.

### 4.2 Fischer-Tropsch Natural Gas to Liquid Fuel, Mossel Bay – South Africa

In the early 1990s, at the request of the South African government, Sasol licensed a GTL process to PetroSA, the South African state-owned oil company. This led to a collaboration with Statoil, a large Norwegian natural gas company and Lurgi, the Germany company that had built the Sasol reactors. Statoil, a competitor to Sasol, having recognized the burden of the relatively low efficiency of the traditional Sasol CTL process, had in 1986 begun a serious research and development effort aimed at an improved second generation F-T catalyst. The partnership of these three companies led to the opening of the first gas-to-liquid fuel plant as a 36,000 barrels per day semi-commercial demonstration project and research center at Mossel Bay, South Africa in 1992. Significant research and testing continued and resulted in a catalyst breakthrough in 2006. This new catalyst system, according to Statoil management, lifted them to a level significantly above competitors. In 2005, Statoil, PetroSA, and Lurgi formed a Swiss-registered joint venture company, GTL.F1, which has since been a leader in gas-to –liquid fuel technology, winning multiple international awards. [1]

Mossel Bay continues to produce approximately 36,000 barrels per day of high quality fuels.

## 4.3 Shell – Bintutu, Malaysia

Royal Dutch Shell, the second largest private energy company in the world, was obviously also interested in using excess natural gas. Many years of research led to establishment of a 14,000 barrel per day commercial plant in Malaysia in 1993. This facility continues to operate at design level and to support research on GTL process improvement. The Air Force Alternative Fuel Certification Office obtained GTL fuel for testing from Bintutu.

## 4.4 The Next Generation

From the early 2000s, planning began on several large scale GTL projects, especially for locations in Qatar and Nigeria where large quantities of natural gas were available but under used. By 2004, at least eight plants were planned with a combined capacity which would have exceeded 500,000 barrels per day. By early 2007, however, most of these projects were cancelled or deferred. Two projects in Qatar involving Marathon and ConocoPhillips were put on hold in 2006. The Qatar Petroleum-ExxonMobil Palm project, 154,000 barrel per day plant, was cancelled in 2007 when the projected $7 billion cost escalated to as much as $18 billion. A 65,000 barrels per day plant, called Tinhert, planned for Algeria was also not advanced. The survivors were, Sasol Oryx in Qatar, Shell Pearl in Qatar, and Sasol-Chevron in Escravous Nigeria.

## 4.5 Sasol Oryx-Qatar

The first large scale GTL F-T operation was the Sasol-Oryx natural gas plant in RasLaffan Qatar. The 34,000 barrels per day, $1 billion joint venture with Qatar petroleum started construction in 2003.

In the absence of significant operating experience, current design models have dictated very large scale facilities. The very size of components has become a daunting challenge. The Oryx F-T reactors built by Yokohama Japan’s Ishikawajima-Harima Heavy Industries are each 60 meters long - the height of a 25 story building - are 10 meters in diameter, each weigh more than 2,000 tons, and each hold three Olympic swimming pools of water.

Seeking an efficiency improvement, Sasol developed new catalysts for this plant. Despite their fifty years of CTL operating experience, the new plant, when commissioned in June 2006, did not work properly. Fine particles separating from the catalyst contaminated the fuel. Interestingly, Statoil claims to have understood and predicted the Oryx plant problem knowing that Sasol was unable to use their patent-protected 2006 second generation catalyst. This observation is included to point out that although the basic concepts of F-T are well understood, the subtle details of the complex process cannot be taken for granted.

Extensive filtering was installed and changes made. The first fuel was ultimately shipped in April 2007 and an operating rate of 7-10,000 barrels per day was achieved. Improvements continued and in March 2009, it was announced that a rate of 29,000 barrels per day was achieved in February 2009.

Qatar Airlines has signed an agreement to power their aircraft with Oryx fuel.

## 4.6 Shell Pearl – Qatar

With the successful opening of the first phase of Oryx in 2006, Qatar petroleum launched their next GTL project - the 140,000 barrels per day Shell Pearl – in July 2006.

Planning for Pearl began in 2004 and is being developed under a development and production sharing agreement. The government of the State of Qatar is covering offshore and onshore costs, and Shell is providing 100% of product production funding which is estimated to be $6 billion. The process will be Shell's proprietary technology developed and used for ten years at Bintutu. The facility will be operated by Qatar Shell GTL Ltd, a Shell subsidiary.

The Pearl site is slightly smaller than New York's Central Park and employs 40,000 construction workers from 50 countries. Production is scheduled for 2011.

### 4.7 Sasol-Chevron - Escravos, Nigeria

A partnership with Chevron Nigeria Limited holding 75% and the Nigeria National Petroleum Company 25% is building a GTL plant that will use over 300 million cubic feet of natural gas each day to produce 34,000 barrels of fuel.

The feasibility study was done in 1998, the design in 2002, construction started in 2005, and completion scheduled for 2009. The cost has increased from $1.7 billion to over $6 billion and the completion date is now scheduled to be 2012.

### 4.8 The Modern Era of Coal to Liquid Fuels

The modern era of coal-to-liquid technology is focused in China. The double digit growth China has experienced has put enormous pressure on their energy sources. Being poor in oil and natural gas, coal has born the burden. Strategic plans and programs have enabled the doubling of coal consumption since 2000, a plan to add 562 new coal-fired electricity generating plants in the next eight years, and a variety of coal-to-liquid fuel projects. Although now modified and substantially reduced, at one point 32 coal based fuel facilities were planned. Collaborations were established with numerous technology companies world-wide and a potpourri of DCL, traditional CTL, methanol, and new variant processes were implemented.

Accurate and consistent information is difficult to get and different sources list different projects. A 2008 briefing by Shenhua Energy Company and a DOE Office of Sequestration, Hydrogen, and Clean Coal Fuels publication *Summary of Activities for Coal-to-Liquid Fuels*, August 2008, both list seven slightly different projects.

### 4.9 Shenhua DCL Pilot Plant and Research Center - Shaghai

Shenhua and two other companies, in 2004, invested $12 million to establish a coal-to-liquid fuel research center in Shanghai. This organization was supported by the U.S. DOE and developed a broad program of technology research, engineering, and training to provide support for the production projects being undertaken. A 6 ton per day pilot plant demonstrated technology elements.

### 4.10 Shenhua DCL – Erdros Inner Mongolia

This 20,000 barrel per day facility, billed as the World's 1$^{st}$ DCL commercial plant, uses an improved DCL process. The feasibility study was completed in 2002, site prep in 2003, and construction started in 2004 with a cost estimate of $1.5 billion.

The design is based on technologies from the U.S. company Headwaters Energy, from Germany and Japanese companies and includes Shenhua innovations. The plant uses Shell gasification, Linde air separation, and liquefication reactors built on-site by China First Heavy Industries. Plans are to progressively increase capacity by a factor of ten.

Both Headwaters and Shenhua have claimed significant advantages over the indirect (F-T) process: [2, 3]

- 30 percent lower capital cost; $62,500 per barrel capacity.
- Inexpensive, highly effective catalyst; conversion rate over 90%; of up to 50% more fuel per ton of coal.
- $35-40 per barrel selling price.
- Up to 50% less plant generated $CO_2$.
- Half the water consumption.

The plant was commissioned approximately on schedule in December 2008, but unfortunately failed after 303 hours of the shake-down in January 2009 and required significant part replacement.  Data has not been released on fuel quality.

### 4.11 COMPS Golden Nest – Baoji, Shaanxi Province

The Centre of Materials and Process Synthesis (COMPS) at the University of Witwatersrand in Johannesburg, South Africa (Wits) – known as Wits COMPS, has developed what they claim is a "novel" modular "advanced Fischer-Tropsch technology."  It is claimed to offer significantly lower capital and operating costs, require less water, and produce 30% less $CO_2$.  The one-pass process uses a fixed bed catalytic system, eliminates the need for significant support equipment including air separation units, and can be used in much smaller flexible applications.

The basic engineering was done by KBR in Johannesburg and the detailed engineering by the Shanghai Chemical Industry Design Institute.  The facility contains five reactors, each 14 meters high and 0.5 meters in diameter.  The plant was built on the site of the BaoDan ammonia plant and uses syngas from that facility.  Neither a design nor achieved capacity has been announced.

The COMPS Golden Nest project was initiated in September 2004, completed in January 2008 and commissioned after the severe winter weather subsided. [4]  Several releases announced the successful start-up, but nothing has been released on fuel quality or quantity.

### 4.12 Shenhua Ningxia and Shenhua Shaanxi – Sasol CTL

Two large 80,000 barrel per day projects represent Sasol's entry into China and the first commercial scale coal-based Fischer Tropsch plants build since 1982.  Planning has been underway for several years, but delayed by the government slowdown.  The nearly identical plants have an estimated cost of $5-7 billion each.  Shenhua and Sasol will each hold half of the investment. [5]

Sasol's Chief Executive Officer, Pat Davies, reported in June 2008 that they had been given go-ahead for the Phase II Feasibility study on the plant to be built in the Ningxia Hui Autonomous Region, but the Shaanxi Province plant is still on hold.  The $300 million (cost shared) study is expected to be finished by the end of 2009.  He said that the Front End Engineering Design (FEED) and the Final Investment Decision would be made within two years of the study completion. [6]

## 4.13 Activity in the United States

A variety of relatively small scale U.S. developers have been engaged in planning large-scale coal-to-liquid fuel projects for a number of years. A few pilot or demonstration facilities have been built and feasibility studies and permitting accomplished. However, carbon control issues, technology risks, and the extremely difficult funding environment have stymied significant progress. The DOE Office of Sequestration, Hydrogen, and Clean Coal Fuels publication *Summary of Activities for Coal-to-Liquid Fuels*, August 2008, lists eighteen coal-to-liquid plant projects – four in engineering design, all the rest (many of which since have been terminated) in the feasibility stage. The following projects are operative.

## 4.14 Rentech

Rentech's stated vision is "to be a global provider of clean energy solutions". They are often credited with having the only fully-integrated synthetic fuel production facility, a 400 barrel per day demonstration unit, currently operating in the U.S.

The company operates an ammonia fertilizer plant and has engaged in a variety of synthetic fuel projects, using the patented Rentech Process, for the past thirty years. The Product Demonstration Unit (PDU) in Commerce City, Colorado has verified high catalyst efficiency and the ability to accommodate natural gas, biomass, and fossil fuel-based feedstocks. It continues to provide fuels for testing and development. Under a recent agreement, ClearFuels Technology Inc will install a 20 ton per day biomass gasifier at the PDU. This latest technology biomass channel will be integrated with the proven Rentech F-T process and UOP's upgrading technology to demonstrate the capability to produce drop-in synthetic fuels from a variety of cellulosic feedstocks.

The Rentech Natchez, Mississippi project will use coal or petroleum coke with at least 5% biomass to produce 28,000 barrels per day of synthetic fuel via the Rentech F-T process. The feasibility study and engineering work have been completed and a long term Enhanced Oil Recovery agreement reached with Denbury Resources to sequester $CO_2$. Permits are expected in 2010 and construction is planned to start before bonds expire at the end of 2010. [7]

## 4.15 Mingo County, West Virginia

The Mingo County Redevelopment Authority is putting together a combination of feedstocks and synthetic fuel production processes to initiate a liquid fuel capability.

The area has readily available bituminous coal and significant quantities of hardwood forestry waste. An announcement was made in November 2008 that Transgas Development Systems (TGDS) will build the $3 billion, 18,000 barrel per day CTL plant with construction to begin in 2010 to be operational by 2013.

TGDS will use two 1,000 MW Direct Quench Prenflo gasifiers licensed from Uhde.

In the initial phase, syngas will then be converted to gasoline using ExxonMobil's methanol-to-gasoline (MTG) process. The Rentech F-T process will be involved with the ultimate goal of producing diesel and aviation fuel. [8, 9]

### 4.16 Ohio River Clean Fuels

Baard Energy is developing a coal and biomass-to-liquid fuels (CBTL) F-T plant in Wellsville, Ohio. The 53,000 barrels per day facility has an estimated cost of $5 billion and is scheduled to begin construction in late 2009.

The plant will be built in three phases with each phase composed of two Udhe gasifiers feeding a single Syntroleum F-T reactor. A single refining process, constructed during the first phase, will service all three phases. A Rectisol system will be used.

The plant is located 20 miles from an oil field and will use the $CO_2$ produced for Enhanced Oil Recovery.

The developer, John Baardson, withdrew from the DOE Loan Guarantee Program March 26, 2009 when DOE announced that loans would not be finalized until legal claims filed by NRDC and the Sierra Club against the Ohio EPA and the U.S. Army Corps of Engineers were cleared. [10]

### 4.17 Syntroleum

Syntroleum is a Tulsa, Oklahoma company that has been involved in renewable energy processing for 25 years. The company has provided more than 300,000 gallons of synthetic diesel to DOE and 100,000 gallons of synthetic jet fuel to the Air Force. The Syntroleum plan is to progressively move to integrated F-T projects where coal gasification costs can be shared by synthetic fuels and other products.

Syntroleun owns both the Syntroleum Process for converting syngas from biomass, coal, natural gas, and other carbon-based feedstocks, and the Bio-Synfining technology for converting animal fat and vegetable oil feedstocks into synthetic liquid hydrocarbons. These processes have been demonstrated to produce a product superior to conventional biodiesel.

The current joint venture with Tyson Foods is building a 5,000 barrel per day synthetic fuel plant in Geismar, Louisiana, to convert animal fats and greases into ultra-clean diesel and jet fuel. Groundbreaking was October 6, 2008 and construction is on schedule and on budget with commercial operations planned for 2010. [11, 12]

Reactors were fabricated in Korea. The estimated cost is $138 million.

### 4.18 Synthesis Energy Systems (SES)

SES is an energy and technology company that builds and operates coal gasification plants. Their proprietary U-GAS fluidized bed gasification technology converts low rank coal and coal wastes into higher value products and is claimed to be efficient at a small scale.

SES has collaborative relationships with Aker Solutions US, a subsidiary of Aker Solutions ASA of Norway and with the China National Chemical Engineering Corporation (CNCEC). These connections have provided international opportunities including the Golden Concord project in Inner Mongolia and the YIMA Coal Industry Group project in Henan Province China.

SES and Consol Energy, the nation’s largest producer of bituminous coal, were teamed to build a coal waste-to-methanol–to-gasoline facility in Benwood, West Virginia. The ExxonMobil MTG process was licensed in September 2008. SES withdrew from the project in October 2008 because of the difficult financial environment. [13, 14]

### 4.19 Headwaters

Headwaters Incorporated is the umbrella for a family of operating companies that have been involved with and championed direct coal liquification-DCL for many years. They were involved in the DOE DCL program and operated a 250- 600 ton per day demonstration plant in Catlettsburg, Kentucky from 1978 to 1982. The DOE recommendation of the DCL process to the Shenhua Group in 1996 started the Headwaters involvement in China, enabled the process license from Headquarters to Shenhua in 2002, and resulted in their continued participation through the December 2008 commissioning.

Headwaters entered an agreement in 2007 with North American Coal Corporation and Great River Energy, a not-for-profit generation and transmission cooperative, to construct a 32,000 barrel per day DCL facility in North Dakota. Initial planning and design was accomplished but in January 2009, the project was put on hold because of regulatory uncertainty. The North Dakota Industrial Commission, that committed $10 million to the project, has given the developer until the end of 2009 to decide whether to move forward. [15]

### 4.20 DKRW Advanced Fuels – Medicine Bow, Wyoming

DKRW in collaboration with Arch Coal is working to develop a liquid transportation fuels facility with an initial production of 15-20,000 barrels per day.

DKRW has a gasification license to use GE coal gasification technology and a license agreement to use the ExxonMobil MTG process for the initial production phase. This is a change from the original plan to produce CTL diesel and aviation fuel. DKRW also maintains a site license to use Rentech technology to produce F-T products. Construction has been scheduled to start in 2010 to come on line in 2013. [16, 17]

### 4.21 Many Stars – Montana

Montana's Crow Nation and the Australian-American Energy company announced on August 8, 2008, an agreement to develop a $7 billion coal-to-liquid fuel project on the Crow Reservation in southeastern Montana. Strongly supported by Governor Brian Schweitzer, the project plans to initially convert 38,000 tons of coal per day into 50,000 barrels per day of ultra-clean diesel, naphtha, and jet fuel. The Crow Nation has over 10 billion tons of coal reserves and plans to ultimately expand to 125,000 barrels per day.

The initial feasibility study has been completed and the permitting process started. Construction is expected to start in 2012. [18]

### 4.22 Observations

Review of the status of synthetic fuel development projects, past and present, offers some interesting observations. The Fischer Tropsch coal-to-liquid fuel process, assumed to be the mature preferred path, has not materialized. The first F-T coal plant, since 1982, has yet to be built! Efficiency, environmental concerns, and capital costs have diverted efforts to other alternatives.

Most operating and under-construction plants:

- Are being sponsored and developed by large oil companies (Statoil, Sasol, Shell, Chevron, ExxonMobil)
    - That have extensive experience with GTL –CTL research and technology.

    - Which are staffed for and have extensive experience with very large projects.
- Are based on partnerships between the development companies and the respective government and are elements in strategic national energy programs.
- Involve significant government financing and government assumption of risk.
- Have the design and engineering work done by major international companies like KBR and Udhe.
- Include extremely large components fabricated in Asia.
- Have experienced significant technical problems and construction delays in spite of the experience.

The planned US plants:

- Have no direct Federal government sponsorship, investment, or assumption of risk.
- Have been constrained by aggressive environmental concerns.
- Are being developed by small companies with marginal financial structures.
- Have connection to US coal companies (Arch, Consol, North American) which operate in a regulatory financial environment.
- Purchase some process and component elements from the major CTL companies (ExxonMobil, Shell).
- Have not found the Sasol and Shell terms & conditions (80 k + bpd, 51+% ownership) generally attractive.

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## 5.0 BUSINESS CASE PERSPECTIVES

### 5.1 Business Environment

The fact remains that the world has and will continue to have an enormous need for energy, and liquid fuels will play a major role. As demand for liquid fuels expands and current sources (mainly petroleum) begin to be depleted or cost and access become significant factors, alternate sources will be needed. When and where the market for alternative fuels will emerge and sustain business investment to meet demand requires careful analysis and informed decision making action.

When building a business case for production of synthetic fuel, and in particular jet fuel, major factors that define the business environment must be recognized, understood, and considered. This situation is depicted in Figure 30.

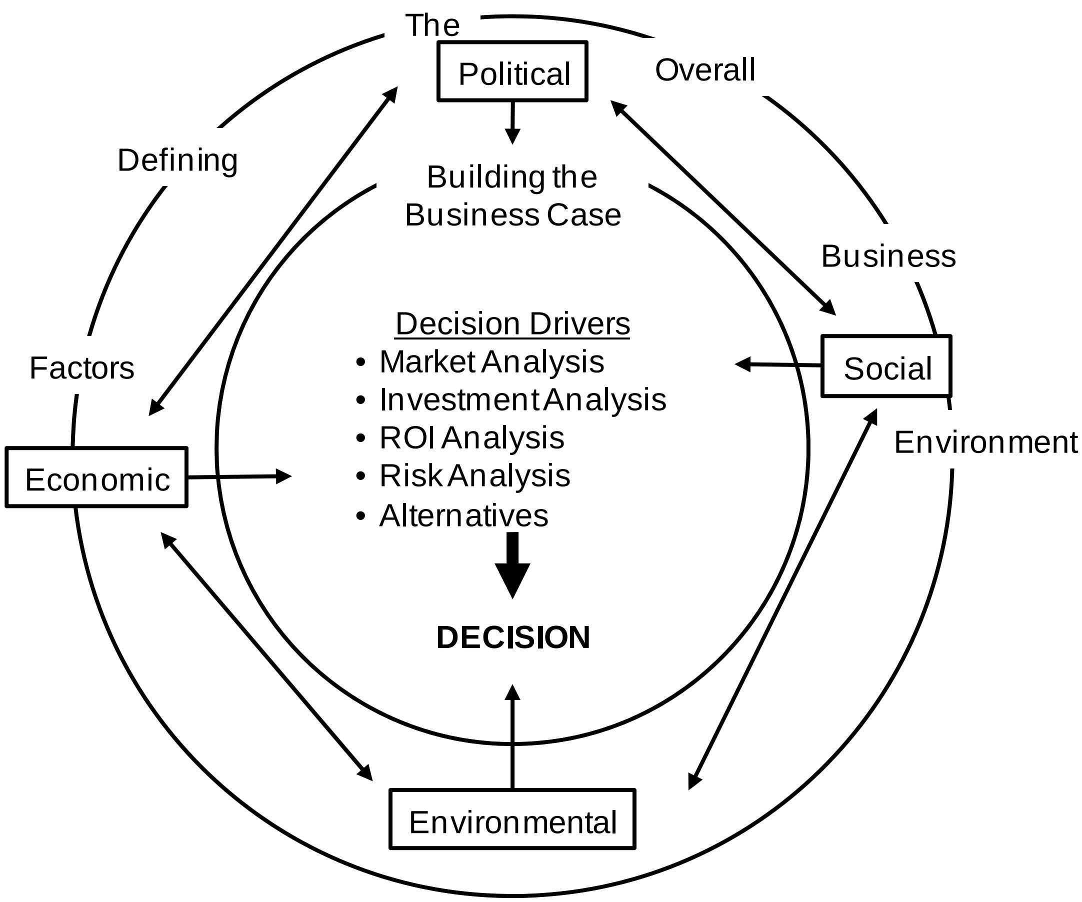



**Figure 30. Business Case Elements**

Building a business case to support a decision to pursue a given potential opportunity must include both an assessment of the factors defining the business environment, and if that analysis supports moving ahead, a detailed analysis of the specific business itself.

### 5.1.1 Understanding The Business Environment Factors

The four factors that define the overall business environment - political, social, environmental, economic- will have a direct impact on and must be considered in each step of the business case analysis. There is a great deal of synergy and cross connectivity among and between these four factors, such that changes in one can, and often does, result in changes in another. For example, increased concerns about environmental issues, such as climate change, can result in changes in social behavior patterns (e.g., transportation method choices), political reaction in the form of generation of regulations and law (e.g. Greenhouse Gas Emission standards), and economic reaction reflected in contraction in certain segments of the economy (e.g., sale of SUVs) and expansion in others (e.g. sale of hybrid vehicles). These dynamics occur on both the domestic and global level. Many of the elements identified below under each factor reflect this cross connectivity.

Political – elements of the political factor that must be recognized and considered include:

- Broad policy (e.g., reduced/increased interference in broad/selected areas).
- Focused policy (e.g., energy: independence; cooperative; incentives; protection).
- Regulations.
- Laws.
- Security concerns.
- Attitudes toward business.
- Competing priorities.
- Influence of special interest groups.
- Election cycle.

Economic – elements of the economic factor that must be recognized and considered include:

- Current and projected economic conditions, both domestic and global.
    - Expansion.
    - Contraction.
    - Protectionism.
- Competitive environment.
- Resource availability.
- Balance of trade.

Social - elements of the social factor that must be recognized and considered include:

- Attitudes toward business.
- Life style – current and projected.
- Concerns over environmental conditions.
- Conflicting/shifting priorities.

Environmental - elements of the environmental factor that must be recognized and considered include:

- Connection to current environmental concerns.
- Special interest groups.
- Potential for future environmental concerns.
- Political climate in reaction to current/potential environmental concerns.
- Attitudes toward business.

Conditions reflecting the influence of these four factors and potential or real resultant impacts on business decisions related to synthetic fuels are now addressed.

### 5.1.2 Business Environment Past, Current, and Emerging Conditions

The U.S. government has repeatedly spent significant sums on alternative fuel research and demonstration projects but allowed short term financial conditions or special interest groups to thwart attainment of a long term capability. The list is long. DOE was established in 1977 to reduce our dependence on foreign oil – the import level in 1970 was 23 % and is now in excess of 60%. There were more than 50 coal gasification projects, of which only two continued beyond the demonstration phase. Nuclear power new construction, despite a safe and successful power generation record, was put on the shelf for more than two decades. Direct coal liquefaction (DCL) was taken to the commercial level in the1980s but terminated in the early 1990s when the price of crude dropped. U.S. tar sands, oil shale, and significant oil and gas deposits have been and continue to be large proven fuel sources but their use has been successfully blocked by special interests. A new site refinery hasn't been built in the U.S. since 1976. Hydrogen has been a very high priority transportation fuel initiative for the past decade, but was recently cancelled. The nation has repeatedly set a goal, brought a product to the table, and then backed away. The short term availability of cheap imported oil has prevailed. FACTORS – POLITICAL; ECONOMIC.

Outside of the U.S., South Africa's F-T fuel in the past, and China's coal-to-liquid fuel and Canada's oil sands industries currently, are examples of strategic national commitment to deal with the need and make the necessary investment to development a capability in spite of short term profitability risk. National funds were committed to not only research but also to the establishment of production facilities. Large scale oil production from Canadian oil sands started in 1967 with production costs of $9-15 per barrel when crude oil prices were less than $10 per barrel. Commercialization was enabled by the Canadian National Oil Policy that established a protected market, sheltered the industry from foreign competition, built refineries, and provided financial support and assurances. It took the better part of a decade for the enterprise to make a profit. Today, the operation is very profitable, provides energy security and quality jobs and provides the major part of the oil exported to the U.S. [1] FACTORS – POLITICAL; ECONOMIC.

Today, in the U.S., the major impediments to the development of "natural" fossil-based or of synthetic fuel supplies are the uncertainty of long term national commitment and the attendant short term business risk of intentional or unintentional crude oil price change. There are abundant sources of energy – if we choose to use them. Without a definitive national energy plan or set of regulatory boundaries or commitment to long term market support, it has been very

difficult for industry to formulate, and get financing for, a viable business case. This situation has been exacerbated by billion dollar facility costs, the recent pervasive recession and environmental climate change concerns. Dr. Daniel Yergin is Chairman of IHS Cambridge Energy Research Associates, received the Pulitzer Prize for his book *The Prize: The Epic Quest for Oil, Money and Power*, and is a frequent expert witness for Congress. In testimony to the Joint Economic Committee of Congress on May 20, 2009 he emphasized these points:

> "As part of a long term view, we need to get beyond the "either/or" energy debate and take a more ecumenical approach – ensuring that a combination of conventional energy, renewables and energy efficiency are all developed with appropriate environmental and climate-change considerations."
>
> "There is no single answer to the energy needs of our $14 trillion economy. Today, fossil fuels – oil, natural gas, and coal – supply over 80% of our total energy. Oil by itself is about 40 percent. That alone makes clear the importance of oil – and the evolution of the oil market – to our economy and security in the decade ahead."
>
> "When we think about U.S. energy security, we need to think about resources on a regional and global scale and thus about the importance of diversification. Even in a down market, the energy security agenda deserves continuing attention. Two new requirements for global energy security are the inclusion of China and India in the energy system, and the greater concentration on physical security of the supply chains and infrastructure."

It is not clear that plentiful low cost fuel is a high national priority. There are multiple indications that higher costs and a lower standard of living are judged to be an acceptable sacrifice for guarding against possible climate change. FACTORS – POLITICAL; ECONOMIC; SOCIAL.

Petroleum didn't get to be the leading energy source by accident. It has been plentiful in many locations around the world and because of its ease of production and distribution, has provided a very cheap energy solution. Technically, the energy density of oil is unchallenged – there is no more efficient way to transfer or carry energy.

Faced with an availability problem, the natural inclination is to look to strong alternatives. Until recently, the second choice was obvious for many reasons. Coal is the overwhelming U.S. energy source. This country has 27% of the world's proven reserves - a greater energy reservoir than Middle East oil – which are conceptually large enough to meet all demands for hundreds of years. Extraction and processing procedures and infrastructures are well developed to support electricity generation. Technology exists, and had been demonstrated, to rearrange the hydrocarbon structure of coal to that of synthetic petroleum. And the basic cost of coal, like oil, was very affordable. FACTOR: ECONOMIC.

Ten years ago, coal was the assumed source, the issues were customary efficiency, logistics, and configuration design trade-offs. However, environmental concerns have changed the scenario. The first decision point is no longer obvious. A complex set of interrelated factors now comprise a complex first step decision matrix. FACTORS: ECONOMIC, ENVIRONMENTAL.

The key business players, the petroleum and coal communities, are vastly different. The petroleum industry is composed of large multinational companies accustomed to geographically diverse operations, large financial investments, and especially to large risk elements. The

process of finding, reaching, producing, transporting, and refining petroleum products involves large management and technical staffs dealing with dynamic events. These organizations are well suited to develop and operate the business and technical structure associated with the CTL ventures that have emerged. In fact, it is these companies that have become the developers of the large natural gas-to-synthetic fuel projects in other parts of the world. To this point, with few exceptions, the petroleum-based energy companies have not seen the need or competitive compulsion to enter the coal-to-synthetic fuel arena. FACTOR - ECONOMIC

In comparison, U.S. coal companies and the closely associated power utility companies they serve are very different. They are generally regional, relatively much smaller, and less sophisticated. Because 90% of coal goes to tightly regulated electric power generation, risk, large risky financial ventures, and new technologies are not major management elements. Multiple product operations are unusual. The prevailing business environment is controlled by government agencies and is risk averse. Discussions with Duke Energy, one of the largest and most aggressive coal processors in the U.S., provided interesting insight. [2] Asked whether a co-located electricity and synthetic fuel facility, which conceptually offers profitability advantages, [R. Williams – Princeton] was considered in the new Edwardsport design, the answer was – “it was considered, but power generation is our business and we think it is best to stick to it.” [Interview, November 13, 2008] FACTOR – ECONOMIC.

The primary current motivation for the development of synthetic fuel is the sudden and meteoric increase in the world crude oil price from under $20 per barrel from WW II until 1973 – a spike to $70 in 1979-1981 - to record high of $147.27 per barrel in July 2008. [3] The primary constraint to the development of a coal-based replacement fuel is carbon dioxide and it’s contribution to climate change. Actions by all three branches of the federal government have created a situation where preventing the release of carbon dioxide will be a mandatory condition for any new coal-based facility. The prevailing context is no compromise, total release prevention from day one. The determination of the environmental protection special interest movement is, in addition to aggressive media campaigns, demonstrated by repeated legal challenges at each project permit and approval step. The support of these challenges by the U.S. court system has made them a reality. A solid and convincing plan for total compliance is mandatory, but may not be sufficient. [4] FACTORS – POLITICAL, ENVIRONMENTAL.

The problems, as described in Section 3, are that the procedures, techniques, underlying policies, and enabling liability determinations for carbon control have not matured and are estimated to require at least a decade. This poses a very difficult challenge for a synthetic fuel plant developer to define a program and then to avoid costly delays in carrying it out. A recent example is John Baardson’s withdrawal from the DOE loan guarantee program because of a Natural Resources Defense Council (NRDC) challenge to a state EPA permit awarded in 2008, which could take years to litigate. FACTORS: POLITICAL, ENVIRONMENTAL, SOCIAL.

### 5.1.3 Emphasis Change

A July 2009 briefing by the Director of Air Force Energy Policy, *U.S. Air Force Use of Alternative Energy,* [5] is an example of the priority emphasis that is being placed on non-fossil fuel alternative sources of fuel.

The current U.S. synthetic fuel business environment, for the many reasons previously discussed –unattractive efficiencies, technical risk associated with large scale and process modification, immature carbon capture and storage technology, uncertain regulatory structure and cost, and the

extremely difficult financing challenge that results - is not making significant progress. The national focus has turned to examination of the options provided by the renewable sources. The renewable candidates are all in early development stages and face significant scale challenges. Thus, until a few months ago they were viewed as an augmentation to enable the environmentally acceptable deployment of a domestic CTL F-T secure fuel industry. Conditions and policy have modified that scenario.

The potential - and huge quantities - offered by the coal and natural gas processes have not gone away, are being continuously improved, and stand ready for crisis implementation. The evidence and activities, however, indicate that, with a few possible exceptions, the decade projected to get CCS to a commercially ready level will be primarily devoted to the shake-out of biomass and algae related processes.

## 5.2 Synthetic Fuel Business Analysis

### 5.2.1 Analysis Considerations

The following is illustrative of the type of elements a business must analyze in determining the viability of a potential business opportunity. The detailed elements may vary from one industry to another, but the basics are fairly common across the business community. This analysis is done only if the analysis of the factors defining the business environment results in a favorable conclusion.

- Is there a market
    - Now, future, who will buy, why will they buy, how much will they buy, what will they pay?
- Assuming there is a market – the market analysis is normally a go- no go decision.
    - How do we provide the solution (product/service)?
        - Product options (in this case CTL, DTL, GTL, MTL, Biofuel)
        - For each option
            - Current state of the art.
            - Single or multiple processes.
            - Public domain or proprietary.
            - Facilities/equipment.
                - Required.
                - Available.
                - Lead time.
                - Cost.
            - Access to transportation.
            - Product compatibility with existing logistics infrastructure.
            - Unique features (in this case reactor vessels and catalysts).

- People/skill sets.
- Raw materials (in this case feed-stocks for conversion).
- Operations.
    - Outputs.
    - Resource requirements (in this case feed-stocks and other materials such as water and hydrogen).
    - Regulatory requirements.
    - Established and recognized product specifications.
- Financing.

▪ Overall risk assessment.

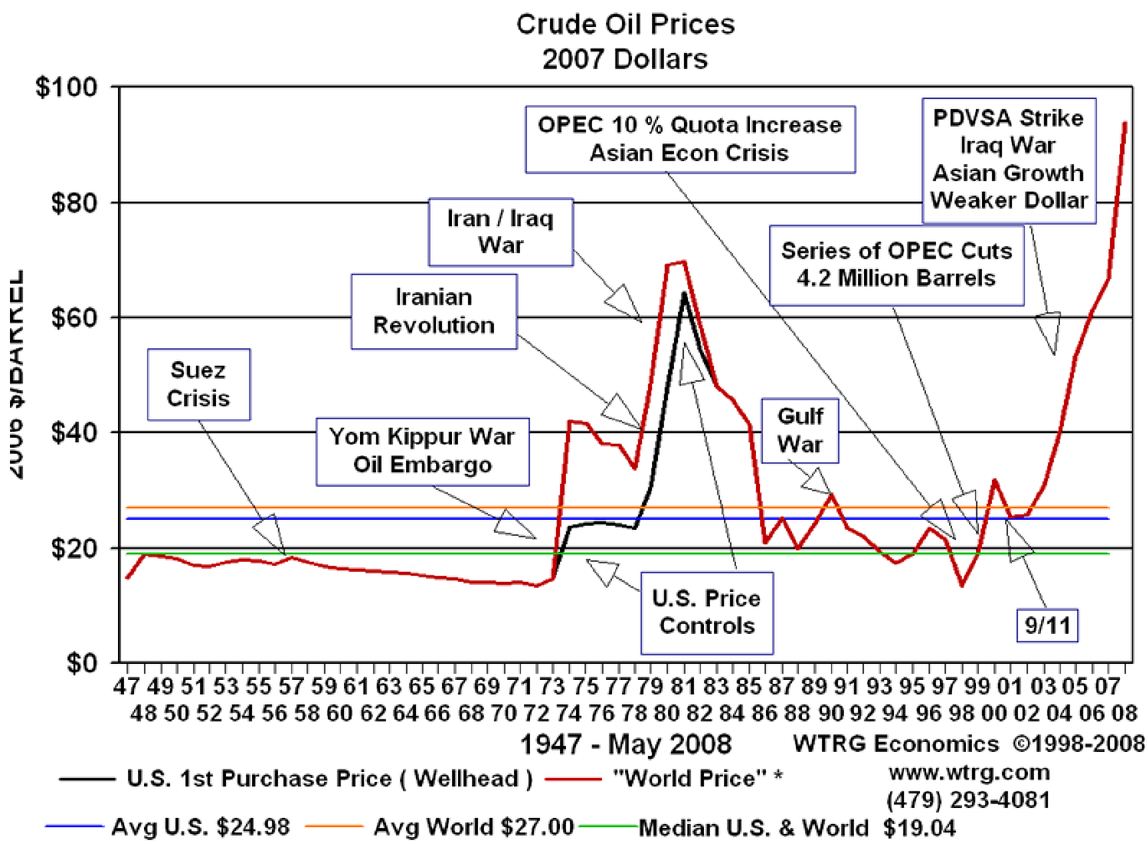
Several of these key analysis elements relative to synthetic fuels are addressed below.

## 5.3 Current Assessment

### 5.3.1 Is There a Market for Synthetic Fuels?

The consensus of a broad range of forecast experts is that, in spite of economic cycles and environmental protectionism, energy demands will continue to increase. The rising expectations of have-not nations are tightly tied to additional energy and fuel. The immediate pressure is coming from China and India but will be followed by many others when economically feasible. Although the life of current oil supply quantities is very difficult to predict, there is wide agreement that quantities are finite and increasingly costly to produce.

There will be a market, but the better questions might be - will there be free market trade, can environmental constraints be met, and will the price be affordable? The market is open to synthetic fuels, but they currently do not have any unique emissions advantages over petroleum-based fuels. Given that the "well-to-tank" emissions of all current fuels are only 20 % of the "well-to-tailpipe" total, even biofuel based synthetics may not have a significant environmental distinction. If there should be a serious effort to reduce total carbon emissions by, let's say, 50%, then the <u>combustion contribution</u> (80%) of any hydrocarbon-based fuel - natural or synthetic - becomes a serious issue. As noted in section 2, a recent NETL document [6] reported that 52% of the crude imported into the U.S. in 2008 would not have met the EISA 2007 Sec 526 restriction. The claim is being made that crude from Canadian oil sands is within 5 % of the average U.S. petroleum crude "well-to-tailpipe" GHG footprint – and continuing to improve. [7] From a U.S. producer or consumer's perspective, the current USAF objective of fuel from a "secure source at a stable price" - <u>price</u> and <u>source</u> - may represent the essential issues. A look at the world price of crude for the last sixty years, Figure 31 indicates that these two factors are not independent.




WTRG Economics (wtrg.com)

**Figure 31. Crude Oil Prices**

#### 5.3.1.1 Where Does Aviation Fuel Stand? Are There Alternatives?

The current efforts to make passenger vehicles cleaner and more efficient could ultimately weaken the demand for gasoline but current technology limits do not extend that possibility to either large diesel or aviation fuel vehicles – neither can operate on electricity. Everything we know today indicates that, regardless of feedstock source, aviation fuel with the current characteristics will be required for a long time. The emergence of synthetic fuels has sparked the question – “if we could design an unconstrained fuel, what characteristics would we like it to have?” Historically, aviation engines have been optimized to take advantage of the inherent petroleum fuel characteristics. Research is beginning to look at what a release from those constraints might yield, but the inertia of the industry and magnitude of the “fleet” will almost certainly affect a gradual transition for even significant improvements.

Another consideration is that a dramatic transition to electric vehicles and mass transportation could create a cheaper, more plentiful crude oil supply to produce diesel and aviation fuel. If the crude price is low and the synthetic fuel business objective is not biased by special security concerns or incentives, there would be several value-risk choices. There are synthetic fuel production processes with lower capital cost, greater efficiency and less risk to produce gasoline - rather than aviation fuel.

The relatively small quantity of military aviation fuel used would not support a strong synthetic fuel market alone. When combined with commercial aviation and the needs for similarly

structured diesel fuel, the demand is and should remain appreciable. The work of the International Civil Aviation Organization (ICAO) projects significant air travel growth and thus a continuing increase in required aviation fuel quantities. [8] This structures the situation where if cost avoidance is the objective, the total demand and the world market should protect the military aviation need. However, if domestic source security is the predominate motivation, the military may have little leverage and be forced to use premium price incentives or "captive" product capacity.

#### 5.3.1.2 The Adequacy of Synthetic Aviation Fuel

Formulation of the Air Force synthetic fuel strategy was accompanied by a test and demonstration program to verify compatibility. The Alternative Fuel Certification Office (AFCO) was formed by Secretary of the Air Force Michael Wynne and is chartered by SAF/IE and AFMC/CC. The office is located in the Aeronautical Systems Center at Wright Patterson AFB, OH.

The AFCO objectives are:

- Support the SECAF goal of certifying the fleet to fly on domestically produced synthetic fuel.
- Manage the USAF fleet-wide certification of alternative aviation fuels and fuel additives. Specifically a synthetic drop-in fuel blend of 50% Fischer-Tropsch and 50% JP-8.

AFCO has developed an extensive process of guidelines and procedures which are contained in Department of Defense Handbook *Aerospace Fuels Certification* MIL-HDBK-510-1(USAF). The certification task encompasses the entire fleet – over 40 separate platforms, all engines, all Support Equipment, and all USAF storage and delivery systems. The process has been defined and is managed by the AFCO, but the actual certification is approved by the individual platform Single Managers.

The AFCO has purchased several quantities of synthetic fuel:

| Supplier | Type | Point of Mfg | Quantity | Date |
|---|---|---|---|---|
| Syntroleum | GTL | Oklahoma | 100,000 gals | 2006 |
| Shell | GTL | Bintutu, Malaysia | 280,000 gals | 2007 |
| Sasol | CTL | South Africa | 400,000 gals | 2008 |

The following chart shows the certification schedule.

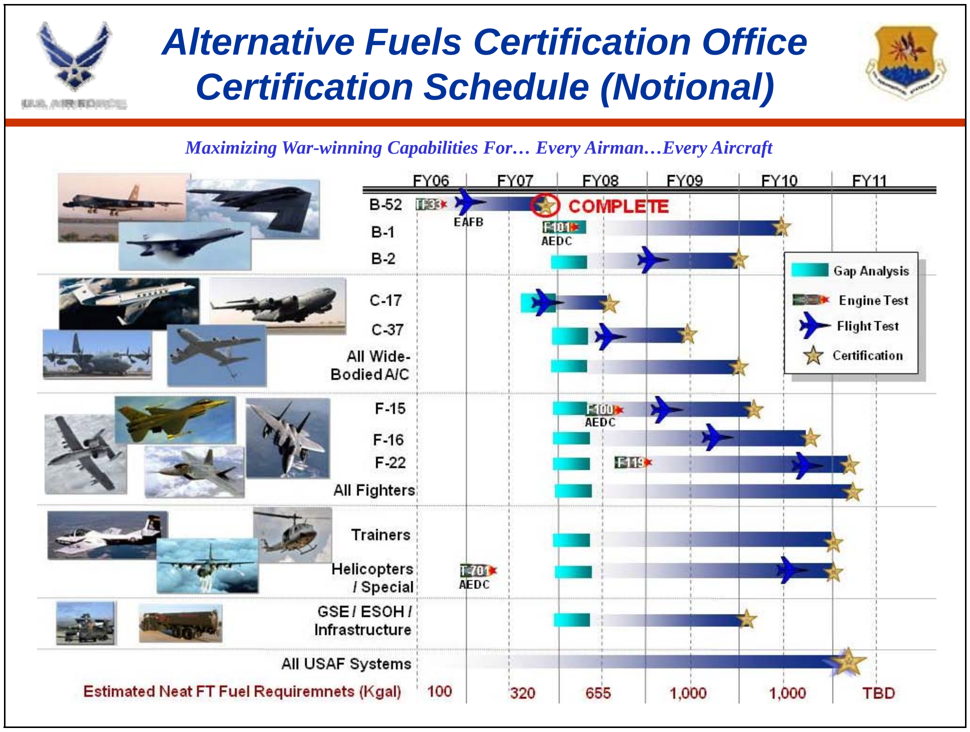



**Figure 32. Alternative Fuels Certification Office Certification Schedule**

The AFCO charter was expanded in 2009 to include the evaluation of Biojet fuel.

### 5.3.1.3 What Are The Specific Fuel Purchase Decision Elements?

There are data from every fuel type and use sector to suggest that cost and availability are the predominant purchase factors. Despite several Congressional attempts, the government seems to be very reluctant to enter long term guaranteed price agreements. Policy advisors, such as RAND, encourage incentives and supports but cautions against long term price agreements. [9] 20 % of the highly subsidized ethanol industry failed in 2008-2009 because of the inability to compete with low cost petroleum. Mid-2009 saw the first exceptions to the long term guaranteed price policy as a small number of coal producing states enacted legislation to provide price guarantees and ensure long term stable coal extraction and coal-based product markets in their region.

The producer challenge remains cost margin. The most significant risk is that the large gap between petroleum fuel extraction-production cost and sale price leaves room for the substantial price variation seen in 2008-2009. The variation can be caused by several factors, including intentional predatory policies.

If the petroleum demand from emerging countries supports the $100 and above per barrel prices projected by both EIA and IEA, then emphasis on fuel source alternatives increase. As shown in Section 3, oil shale and other unconventional sources can overcome their economic and environmental disadvantages and be competitive at this price level.

### 5.3.2 Factors Affecting Production Choices

#### 5.3.2.1 Location

Siting of a synthetic fuel plant must consider several location elements. Common to locating all manufacturing facilities is the logistical or transportation balance between material source and product market. Even moderate size synthetic fuel plants use huge quantities of feedstocks. A typical 30,000 barrel per day coal-based Fischer-Tropsch plant would use between 15,000 and 30,000 tons of coal each day. A similar sized natural gas based plant would use 300 million cubic feet of natural gas each day. Even a 5,000 barrel per day biomass plant would require 3,000 tons of corn stover or switchgrass each day. Connection to rail, pipeline, or major highway and on-site storage for as much as sixty days, would be mandatory. The distance from the source is also a strong factor.

The following map illustrates the geographic and type location challenges associated with coal.

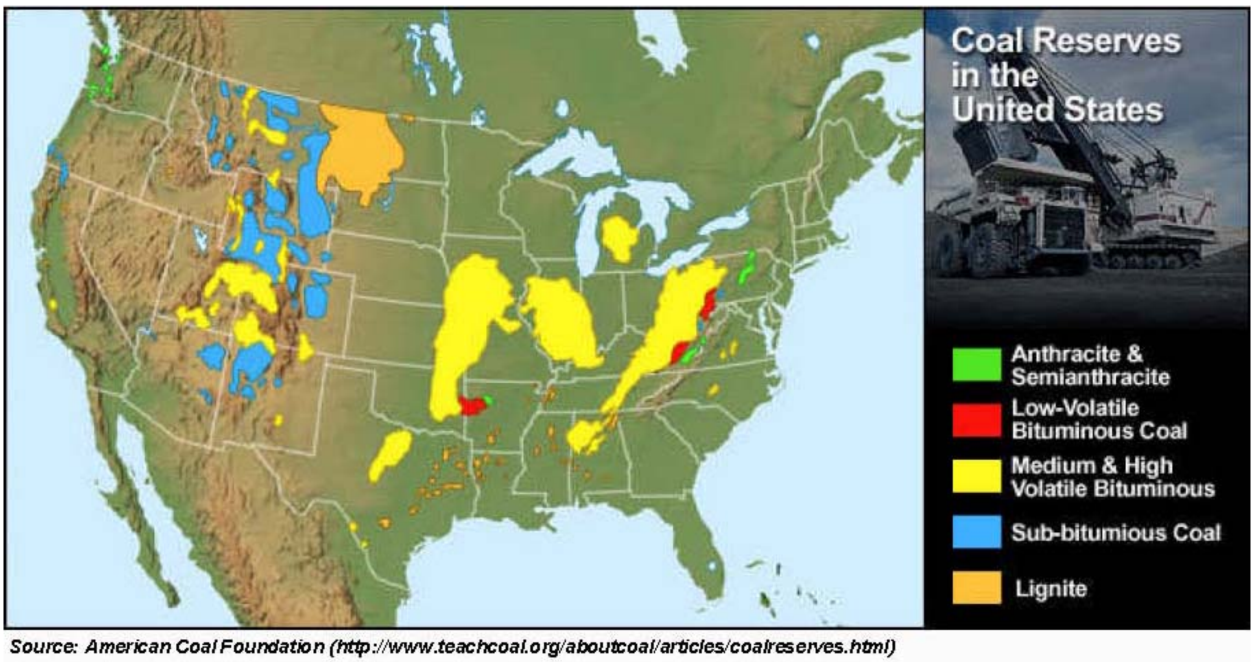



**Figure 33. U.S. Coal Resource Locations**

Distributing 30,000 barrels per day of fuel would require 42 rail tank cars a day or pipeline connectivity. The importance of ensuring continuous plant operation would also require a quantity of on-site storage for each of the family of resulting fuels and accompanying products.

The relatively new requirement is surge storage and pipeline connection to a carbon re-use or sequestration site. The 30,000 barrel per day coal facility would produce up to 19-37,000 tons or 332.2 – 646.8 million cubic feet per day of carbon dioxide.

Water supply is also important. The 30,000 bpd coal facility would require up to 6.3 million gallons of water a day. Unfortunately, western U.S. locations that provide economical and easy to recover coal, are also water shortage areas. Moves by large petroleum companies to secure western water rights in anticipation of shale oil extraction are already causing political and legal actions.

Location size is another item. The preliminary design of a 40,000 barrel per day CTL-GTL plant covered a little more than 400 acres. The 140,000 barrel per day Shell Pearl GTL plant in Qatar occupies a site slightly smaller than New York's Central Park.

### 5.3.2.2 Production Quantity

In the absence of any extensive operating experience, the analytical design models being used today place significant importance on large scale. Table 11 shows the capital and operating costs attributed to several possible plant capacities. Although there is some confidence in the relative comparison, significant cost increases in the past three years makes the absolute numbers questionable.

**Table 11. Plant Scaling Analysis**

| Coal Tons Per Day | Potential F-T Liquid Output, BPD | Illustrative Capital Cost,* USS Million | Capital Cost Per BPD Output S/BPD |
|---|---|---|---|
| 300 | 500 | $200 | $400,000 |
| 1,200 | 2,000 | $400 | $200,000 |
| 3,000 | 5,000 | $800 | $160,000 |
| 6,000 | 10,000 | $1,300 | $130,000 |
| 20,000 | 30,000 | $3,000 | $100,000 |
| 30,000 | 50,000 | $4,000 | $80,000 |

Source: SAIC based on NETL data.
Capital cost is mid 2006 dollars and includes $CO_2$ capture, but not compression and
* storage, or sequestration.

Indiana Coal Report, 2009

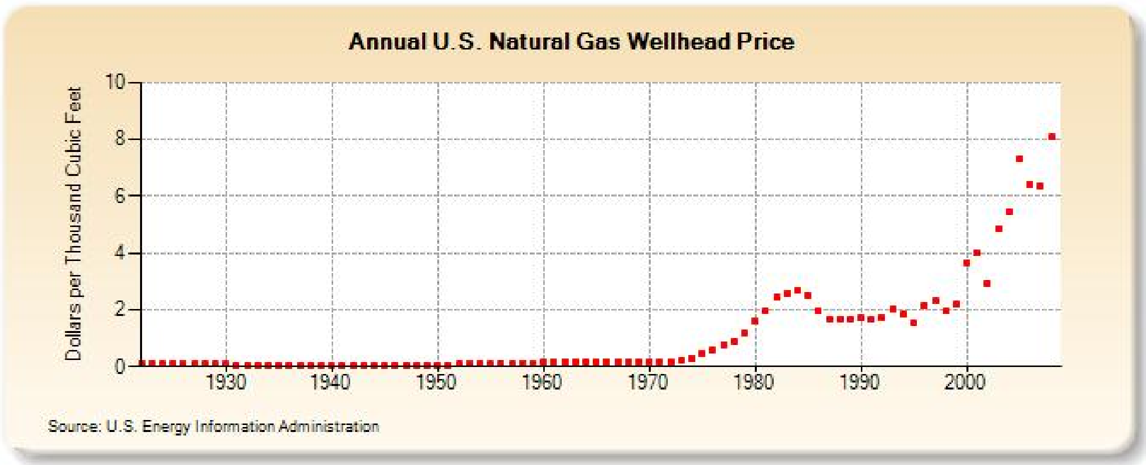
A smaller plant would make initial capital costs and the costs that would accompany construction delay much less but, according to current models, greatly increase pay-back time.

The restrictions, costs, and liabilities associated with yet to be defined carbon control requirements make consideration of non-traditional high efficiency - lower carbon emitting - processes attractive even if their output is relatively small. Several new technologies, like micro channel F-T, coal refining, and plasma gasification, hold real promise and must be part of the decision matrix.

### 5.3.2.3 Feedstock

A major element of the decision matrix is feedstock choice. The preceding sections have highlighted the technical process differences of using coal, natural gas, and biomass in synthesis processes. Added to these technical advantages and disadvantages are availability and cost. Large low cost amounts of a particular feedstock controlled by a potential plant development partner carry large weight.

Sources that have particular issues in the regular market - like stranded natural gas, high sulfur coal, and timber waste- have provided unique, highly attractive business opportunities. Given the high capital cost, the assurance of long term quantity and long term cost will also be very important. Currently natural gas- GTL – would make an excellent synthetic fuel choice, but because it has many advantages and is the easy choice for many different applications – especially as a coal replacement for electricity generation – cost and availability could change drastically.




[EIA, Natural Gas Navigator, Price View History]

**Figure 34. Annual U.S. Natural Gas Wellhead Price**

Specifically because of many new and convenient uses, the price escalation seen in the past ten years is expected to continue. The wellhead price was approximately \$2 per thousand cubic feet through the 1990s, it went to \$3 in 2003 and then \$8 in 2008.

Given the unsettled carbon control regulatory situation, biomass will be a mandatory component of any synthetic fuel production. As previously mentioned, the work of Dr. Robert Williams at the Princeton Environmental Institute has shown that co-firing a relatively small amount of biomass with coal can significantly change the carbon footprint and may be the difference in meeting the legislated EISA 526 or similar GHG footprint mandates. [10]

### 5.3.2.4 Internal – External Power and Hydrogen

The inherent constituents of coal and low efficiency of traditional coal-based Fischer Tropsch synthesis poses a power source issue and opportunity. The use of oxygen for gasification rather than air prevents the formation of nitrous oxides which then don't need to be cleaned out of the resultant syngas. An Air Separation Unit can represent 20% of the capital cost and take a significant percentage of the accessory power to operate it. [11]

Since gasification is very endothermic, the heat necessary to make it run is often obtained by using as much as 30% extra coal. This exacerbates the already serious $CO_2$ and water quantity problems. If economical external power is available to operate the air separation unit (ASU) and provide heat for the gasification, the fuel output is much greater and carbon-dioxide by-product much less. Likewise, if hydrogen can be imported rather than generated by water-shift, the energy balance and yield are much better.

Conceptually, the collocation of an energy and hydrogen needy CTL plant with a nuclear power plant where excess heat is a problem, would be a wonderful collaboration. Although technically elegant, the huge capital costs and the integration of distinctively different operating and regulatory communities is beyond practical private industry consideration. It would take a government initiative like the integrated coal mining-electric power-synthetic fuel programs taking place in China.

### 5.3.2.5 Production Process

Closely related to target product and feedstock, is specific process. The measures of merit include – availability, maturity and risk, capital and operational cost, selectivity, efficiency, CCS burden, lead time, and scale. There are two major pieces of the production system – the syngas preparation function and the fuel synthesis function.

Natural gas requires some preparation and cleaning but nothing compared to coal. Coal gasification technology could be the most important factor in a CTL plant design. There is continuing development but a relative few have been commercially proven: Lurgi fixed bed gasification, Texaco entrained flow gasification using coal-water slurry, and Shell entrained flow gasification using powdered coal. The following charts show configurations.

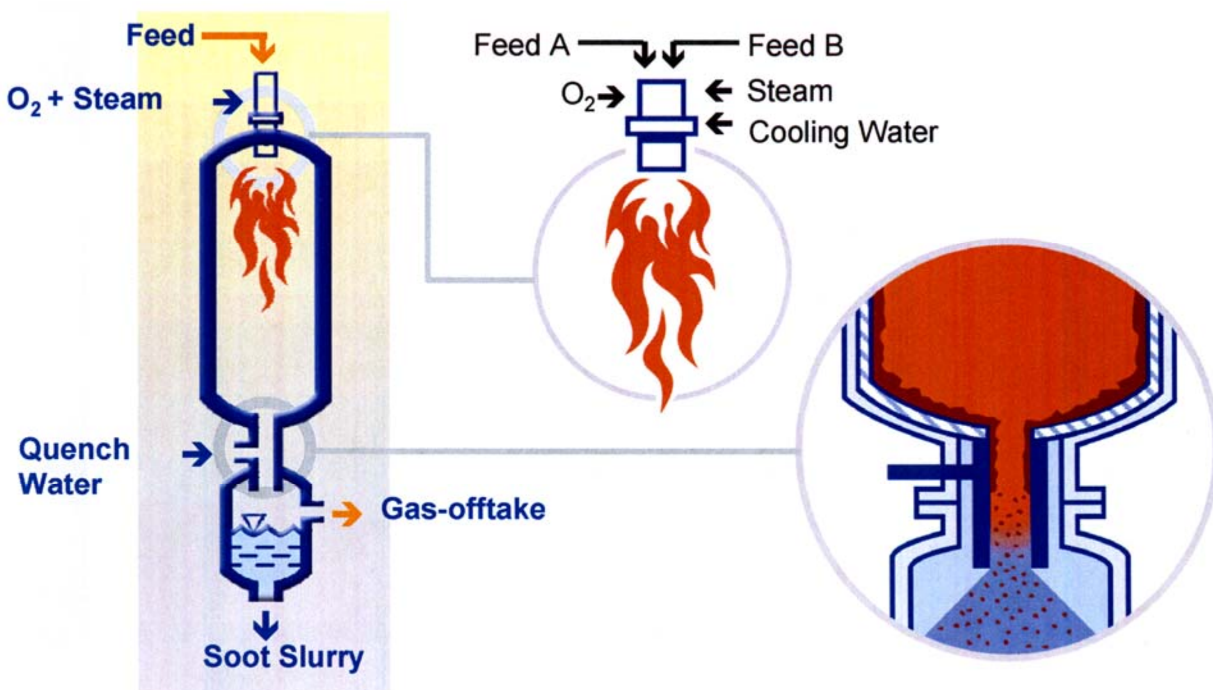



**Figure 35. Lurgi Multi-Purpose Gasification (MPG)**

Lurgi has built the Sasol gasifiers since 1954 and claims that 75 % of the syngas from coal is produced in this type of reactor.

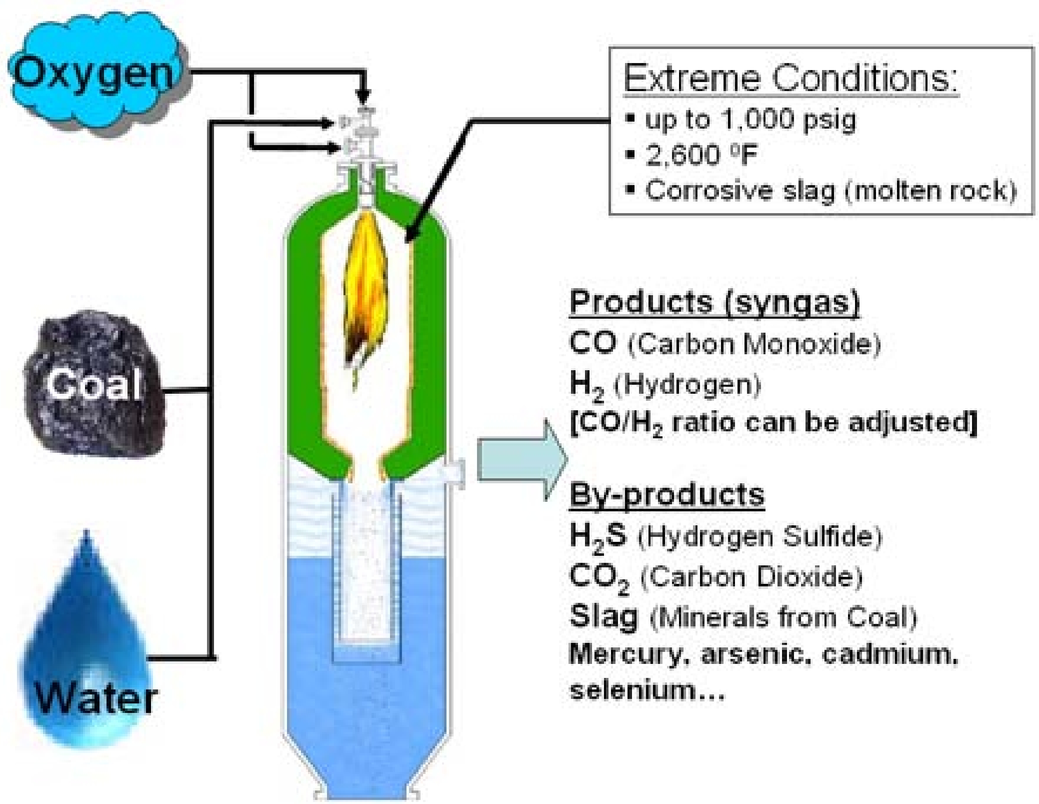



**Figure 36. Generic Gasification**

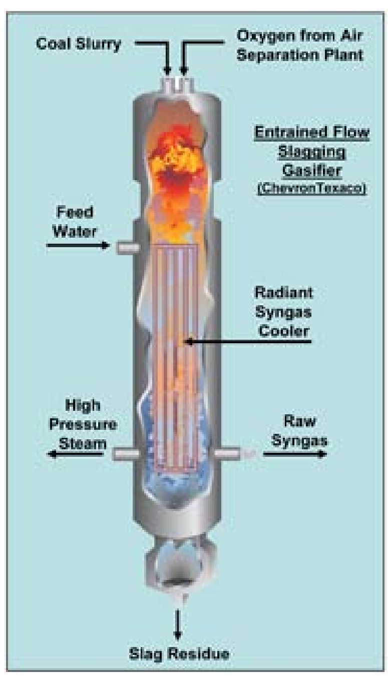



**Figure 37. Chevron Gasifier**

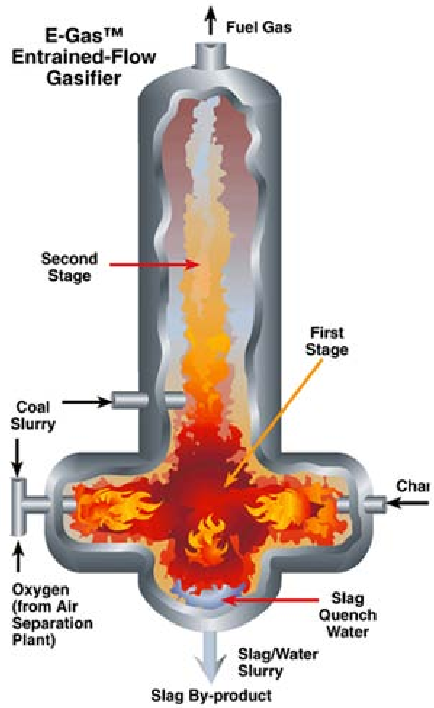



**Figure 38. Conoco Phillips E-Gas Gasifier**


**Figure 39. Transporting Tampa Gasifier**

As shown in Figure 39, gasifiers are very large and very heavy.

**Synthesis Processes**

Converting syngas to synthetic crude (syncrude) is the next step. The Fischer-Tropsch process is the major path from coal to liquid fuels and has been the only suitable path for aviation fuel. As with gasifiers, F-T reactor variations continue to emerge but are still generally represented by the four major types:

- Multi-Tubular Fixed Bed reactor.
- Circulating Fluidized Bed reactor.
- Fixed Fluidized Bed reactor.
- Fixed Slurry Bed reactor.

Simple diagrams of each of these reactors are shown in Figure 40 below. [12]

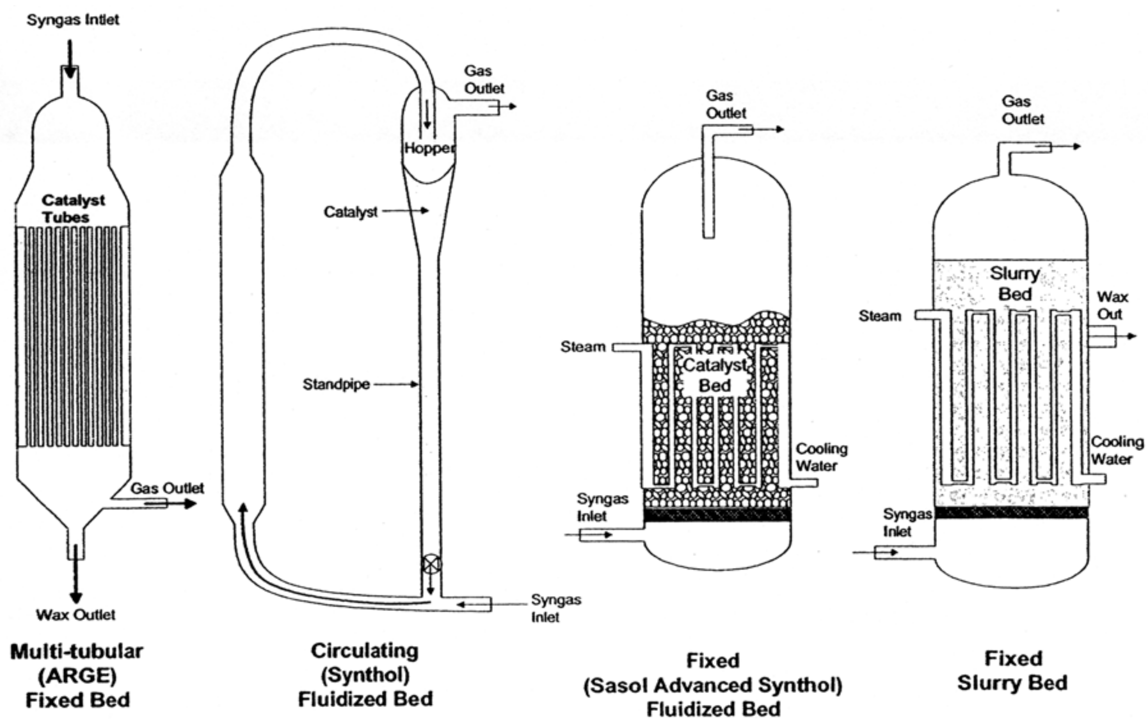



**Figure 40. Types of Fischer-Tropsch Synthesis Reactors**

NOTE: there have been and continue to be ongoing efforts to further refine F-T reactor designs and related processes. Variations of these four types continue to be pursued, but these remain the basic fundamental reactor approaches.

Fundamentally, the F-T reactor vessel enables the conversion of syngas to synthetic crude. There is a high temperature F-T process (HTFT) and a low temperature F-T (LTFT) process. High temperature F-T is used to produce a light syncrude and olefins. Low temperature F-T is used to produce a syncrude with a large fraction of heavy, waxy hydrocarbons. Reactor design is very complex and must take into account the conditions needed for F-T catalytic conversion, the properties of the syngas used and those of the syncrude produced. [13] In basic terms, in a F-T reactor syngas is circulated through the catalyst beds stimulating the synthesis reaction and the

formation of fluids or waxes. The highly exothermic F-T reactions generate a large amount of heat. Removal of this heat while obtaining high conversion rates is the challenge of reactor design. Recent moves away from fixed-bed to slurry bubble column reactors (SBCR) has been motivated by heat removal.

The basic tubular fixed bed reactor design has been in use since WWII. It can use either an iron-based or a cobalt-based catalyst. Reactor beds are 10 to 12 meters long. The reactor resembles a tubular heat exchanger, with catalyst packed in the tubes. Temperature control is very important to prevent damage to the catalyst. Tubular fixed bed design is used in low temperature F-T applications. Syngas enters the top of the reactor, flows through the tubes, and products exit at the bottom of the reactor. Iron catalyst life span is 70-100 days, and removal is very difficult. Sasol uses a tubular fixed bed design called the ARGE high capacity F-T reactor, and uses iron as the catalyst. Shell has a tubular fixed bed reactor design known as the SMDS process, which uses cobalt as the catalyst. [14]

The Circulating Fluidized Bed reactor is used in high temperature F-T. These reactors are also known as Synthol reactors, based on a design by Kellogg and extensive Sasol experience. Sasol reactors are 3.5 meters in diameter and 38 meters tall. Syngas enters the bottom and entrains catalyst that is flowing down the standpipe. High gas velocity carries the entrained catalyst into the reaction zone, then further into a large diameter hopper where catalyst settles out and the product gases exit through a cyclone. Circulating Fluidized Bed reactors are extremely complex and involve circulation of large amounts of catalyst which leads to erosion in several areas of the reactor. They also appear to have reached their capacity limit at 7,500 BPD [15].

The fixed fluidized bed reactor has been developed by Sasol, is referred to as the Sasol Advanced Synthol reactor, and has replaced the circulating fluidized bed Synthol reactor. Syngas is introduced through a distributor and bubbles up through the catalyst bed. Process conditions are similar to the Synthol reactor. These reactors are half the cost and size of the circulating reactors. Catalyst consumption is 60% less and maintenance cost is 85% less. They have better thermal efficiency with a less severe temperature gradient, as well as a lower pressure drop across the reactor. Operating costs are considerably lower and there is greater process flexibility in terms of product distribution. [15, 16]

Fixed Slurry (bubble column) Bed reactors are used in low temperature F-T. These are three phase reactors that consist of a solid catalyst suspended and dispersed in a high thermal capacity liquid. Syngas is bubbled through the liquid phase achieving excellent contact with the catalyst while keeping the catalyst particles dispersed. This design has several advantage compared to fluidized bed reactors. Among these are better temperature control, lower catalyst loading, and significantly lower catalyst attrition rates. Sasol's Slurry Phase Distillate (SSPD) reactor has been in commercial operation since 1993. The reactor has a diameter of 5 meters and is 22 meters high. Two reactors are in operation in Ras Laffan, Qatar. The SSPD technology is preferred for commercial conversion of natural gas to synfuels. [17]

Table 12 provides data from Sasol showing a comparison of the application of the various reactor types. This data helps one appreciate the size of the vessels, their level of maturity based on when they began operation, and their production capability. Entries in the "reactor Type" column convert as follows:

- SAS – Fixed Fluidized Bed.
- CBF (Synthol) – Circulating Fluidized Bed.
- Arge – Multi-tube Fixed Bed.
- SSDP - Fixed Slurry (Bubble Column) Bed.

Note each reactor type is also shown as it associates with either high temperature F-T or low temperature F-T. As noted earlier, high temperature F-T is used to produce a light syncrude and olefins, and low temperature F-T is used to produce a syncrude with a large fraction of heavy, waxy hydrocarbons. [18]

**Table 12. SASOL Fischer-Tropsch Reactors**

| Process Types | Reactor Type | Dimensions | Weight | Year On-Stream | Capacity, BPD | Real/ Claimed/ Design | References |
|---|---|---|---|---|---|---|---|
| HTFT | SAS | 5m diam x 22m height | N.A. | 1989 | 3500 | Real | [Geertsema], [Ganter2005] |
| HTFT | SAS | 8m diam x 38m height | N.A. | 1995 | 11000 | Real | [Geertsema], [Ganter2005], [Zhang_etal2000] |
| HTFT | SAS | 10.7m diam x 38m height | N.A. | 1999 | 20000 | Real | [Geertsema], [Ganter2005], [Zhang_etal2000] |
| HTFT | CBF (Synthol) | N.A. | N.A. | 1955 | 2000 | Real | [Ganter2005] |
| HTFT | CBF (Synthol) | N.A. | N.A. | 1982 | 6500 | Real | [Ganter2005], [Zhang_etal2000] |
| HTFT | CBF (Synthol) | N.A. | N.A. | 1991 | 7500 | Real | [Ganter2005], [Zhang_etal2000] |
| LTFT | Arge | N.A. | N.A. | 1955 | 500 | Real | [Ganter2005], [Zhang_etal2000] |
| LTFT | Arge | N.A. | N.A. | 1987 | 700 | Real | [Ganter2005], [Zhang_etal2000] |
| LTFT | SSDP | 5m diam x 22m height | N.A. | 1993 | 2500 | Real | [Ganter2005], [Zhang_etal2000] |
| LTFT | SSDP | ~ 10.7m diam x 38m height | N.A. | N.A. | 10000 | Claimed | [Geertsema], [Zhang_etal2000] |
| LTFT | SSDP | 10m diam x 60m height | 2200 tons | 2006 | 17000 | Real | [Ganter2005] |

There are other synthesis processes in existence and use today. The Exxon Mobile menthol-to-gasoline (MTG) process is an example of a synthesis system that has demonstrated low capital cost, quick construction, trouble free start-up, and high selectivity of a single, directly marketable product. Even though the product is gasoline and not easily up graded to diesel or jet fuel, it makes a very attractive alternative in today's uncertain environment. Several U.S. developers who started with F-T CTL have changed, at least for their first phase, to MTG.

The overriding issues with regard to gasification and synthesis, the primary elements of the conversion of a variety of feedstocks to synthetic crude, are the size of the pressure vessels (reactors), sources for their manufacture, and their cost. A look at the current industrial base reveals that at the present time there is no capability in the United States to produce the required reactor vessels. Available assessment of our industrial base capability has been focused on the needs of nuclear power. Pressure vessel sizes and capacities for that industry are basically identical to those needed for synthetic fuel gasification and synthesis pressure vessels/reactors. Both depend on the same forging and fabrication capability. The supply challenge is not limited to the heavy forgings for pressure vessels, but extends to other engineering components as well.[19]

Renewed emphasis and actual investment in new nuclear power generation facilities in the U.S. and abroad is resulting in investment to increase needed capacity. The current very heavy forging capacity is in Japan, specifically Japan Steel Works (JSW), China (China First Heavy Industries), and Russia (OMX Lzhora). Capacities for nuclear pressure vessels require forging presses of 14-15,000 tons which can accept steel ingots of 500-600 tons. Current throughput at JSW is four vessels per year, although there are investment plans in place to expand. Other efforts are underway that will increase available capacity. Details on several of these efforts are provided in Table 13 below. [20, 21]

**Table 13. Pressure Vessel Capacity Investments**

| Company | Location | Description/Value | Capability | Timeframe |
|---|---|---|---|---|
| Westinghouse (Global Modular Solutions) | U.S. | Joint venture with Shaw group – new plant in Louisiana | Modules for AP1000 reactors | 2009 |
| Babcox & Wilcox Nuclear Power Generation Group (B&W NPG) | U.S. | Claims to be sole N. American manufacturer of large pressure vessels. | Producing EPR components for Areva of France in Mt. Vernon, Indiana plant. | On-going |
| Northop Grumman | U.S. | New factory at Newport News, VA. Joint venture with Areva - $360M | Receives major components and finishes them for installation | 2011 |
| Japan Steel Works (JSW) | Japan | Expanding Muroran plant – PH 1 - $523M; PH 2 - $314 | Nuclear reactor pressure vessels | Phase 1 – 2011<br>Phase 2 - 2012 |
| Mitsubishi Heavy Industries (MHI) | Japan | Doubling capacity - $138M | Nuclear reactor pressure vessels | 2011 |
| China First Heavy Industries (CFHI) | China | Expanding - $337M | Nuclear reactor pressure vessels | Started in 2008 |
| Donfang Boiler Group Co Ltd | China | New factory – $ unk | Nuclear piping, structural and equipment modules for Westinghouse AP1000 design | 2008 |
| Larsen and Toubro Ltd | India | Venture with state-run Nuclear Power Corp of India (NPCIL) - $463M | Nuclear forgings | Unknown |
| Group led by Reliance Power, NPCIL, and Bharat Heavy Electricals (BHEL) | India | Expand base in nuclear energy sector - $50B | Various nuclear related | 2008 - 2013 |
| Bharat Heavy Electricals (BHEL) | India | New plants - $7,5B | Components for 1,600 MWe reactors | 2009-2010 |

**Table 13. Pressure Vessel Capacity Investments *(Cont'd)***

| Company | Location | Description/Value | Capability | Timeframe |
|---|---|---|---|---|
| Bharat Forge Ltd | India | Joint venture with Alstom – state of the art – 14,000 ton press | May include nuclear components | 2011-2012 |
| National Thermal Power Corp | India | Will diversify into nuclear power | Various nuclear related | 2008 |
| Areva | France | Purchased France's SFAR Steel | Plan to produce very heavy mechanical components, up to 11,300 tons, including reactor pressure vessels | 2006 |
| Creusot Forge, subsidiary to Areva | France | Investing to increase heavy nuclear components – up to 500 ton ingot | Various nuclear related | 2008 - ?? |
| Sheffield Forgemasters | U.K. | Looking at financing to add a 15,000 ton press, handles 500 ton ingots | Heavy components for EPR and AP1000 reactors. | 2009-2012 |
| OMZ Komplekt-Atom-Izhora | Russia | Doubling capacity - $430M. Rebuilding their 12,000 ton press, increasing to 15,000 tons | Forgings for all domestic reactors – 4/yr from 2011 | 2011-2016 |

The fundamental processes needed to generate synthetic fuel, i.e., gasification and synthesis, are available, but continue to require in some cases maturation, and in others continuing refinement. In the majority of cases, capital cost are high and lead times for major components are lengthy. While factors are changing that landscape, in the near term these are significant factors in any business case analysis that must be weighed against the potential for long term business success.

#### 5.3.2.6 Catalysts

Connected to process, equipment, and efficiency are catalysts. The Statoil story and Sasol-Oryx start-up problems (Section 4.2.1) are recent examples of F-T catalyst importance. Overall efficiency, selectivity, and yield are all results of catalyst effectiveness. The quality of a catalyst is measured in terms of effectiveness, durability, and cost. The Sasol operation from the 1950s to present use the relatively durable and cheap iron based catalysts. However, as discussed several times, the quest for improved efficiency and all the benefits it brings, has turned the industry back to cobalt despite its much greater cost and limited supply. Some of the catalyst particles used are the size and consistency of talcum powder. To minimize the quantity, maximize the exposure to the syngas being excited, and withstand the violent reaction process, these fine particles are carried on a support structure that has normally been alumina. The configuration of the structure and bonding of the two elements are critical parts of the much researched and highly protected catalyst art. In most cases, a developer would chose and license a vessel-process-catalyst combination.

### 5.4 References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## 6.0 INITIATIVES, POLICIES, REGULATIONS, AND LEGISLATION

Any consideration of making synthetic fuels available to meet Air Force aviation requirements must address the various legal and related activities that impact the entire area of alternative fuels. The vast majority of initiatives, policies, regulations, and laws have their genesis in the environmental and, to a lesser extent, the national security aspects of pursuing synthetic fuels.

The various methods for generating nonpetroleum-based fuels described earlier bring with them not only the opportunity to produce various liquid fuels from sources other than petroleum, but also the attendant generation of other outputs, some of which are not desirable. Some of these outputs are classified as greenhouse gases (GHG) that make up part of the atmosphere around the earth. These gases, as defined by the U.S Department of Energy, include: [1]

- Water vapor
- Carbon dioxide
- Methane
- Nitrous oxide
- Ozone
- Chlorofluorocarbons (CFCs)

Increases in the concentration of GHGs is being considered as a primary causative factor in the global warming arena. One gas of particular interest is carbon dioxide ($CO_2$), which is generated in varying amounts by the processes used to produce synthetic fuels. Other GHGs are also generated in one or more of the various synthetic fuel production processes. It is important to note that petroleum-based fuels also contribute to GHGs, and $CO_2$ in particular, in both production and consumption.

Carbon dioxide levels as parts per million (PPM) of the atmosphere are impacted by both natural and anthropogenic activities. The latter, that which is attributable to human activity, is considered the primary reason for measureable increases in $CO_2$ PPM levels in the atmosphere. The U.S. Environmental Protection Agency (EPA) ranks the major GHG contributing end-user sections of the economy in the following order (their % contribution is also shown): [2]

- Industrial - 27%
- Transportation - 33%
- Residential - 12%
- Commercial - 18%
- Agricultural - 9%

The concerns over climate change and the link to GHGs has resulted in the generation of a wide variety of initiatives, policies, regulations, and laws. The vast majority of these focus on efforts to reduce GHG levels, again with specific emphasis on $CO_2$. The following provides information on activities at the international, U.S. Federal Government, and state and local levels with regard to initiatives, policies, regulations, and laws. As with the overall subject of synthetic

fuels, the initiatives, policies, regulations, and laws area is very dynamic and changes rapidly, requiring constant monitoring in order to stay abreast of the current status.

**International**

There are two major international agreements dealing with emissions and efforts to control their output and resulting environmental impacts. These agreements are the Kyoto Protocol and the Montreal Protocol.

The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC). The protocol is a treaty which establishes legally binding commitments for the reduction of four greenhouse gases: carbon dioxide, methane, nitrous oxide, and sulfur hexafluoride. Basically, the protocol sets goals for GHG reductions by the larger industrialized/developed economies (called Annex I economies). The reductions are measured against each nation's 1990 emissions levels. The protocol establishes a cap-and-trade mechanism by which nations that are exceeding their required carbon levels can buy carbon credits from nations that are below their required levels. The United States is assessed a 7% reduction. The U.S. has not ratified the protocol based first, on concerns that China and India, two of the biggest GHG generating nations, are not levied any reductions, and second, over concerns that efforts to achieve the required reduction would hurt the U.S economy and reduce our Gross Domestic Product (GDP). [3]

The Montreal Protocol is a treaty focused on the scientific evidence that chlorofluorocarbons (CFCs) and related substances, i.e., hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs), have caused thinning of the ozone layer in the atmosphere. The treaty calls for the establishment of limits on use and production, and the eventual phase-out of use and production of these substances, except in very special and limited applications such as asthmatic inhalers. Parties to the treaty agreed to freeze consumption and production of HCFCs by 2013 and to start reductions in consumption and production by 2015. [4]

**United States**

Federal Government level – there have been several responses to the overall need to look at the subject of energy. While the U.S is not yet a ratifier of the Kyoto Protocol, we have put in place mandates through legislation that address efforts to deal with emissions. Since production and use of synthetic fuels are contributors to GHGs, the processes associated with these fuels must take into account the need to deal with legislative requirements. Table 14 provides a summary of requirements currently in force that address emissions. It should be noted that the details are very extensive and complex, and for a more thorough understanding one should read the actual documents. [5, 6, 7, 8, 9, 10]

NOTE: **bold** font used to indicate connections to synthetic fuels.

**Table 14. Federal Initiatives/Requirements**

| Policy/Program/Law | Area Addressed | Requirements |
|---|---|---|
| Clean Air Act [5] | 1963 – set emission standards for stationary sources<br><br>1965/66/67/69 - amended each year to address mobile sources, support R&D, & set compliance deadlines for stationary sources<br><br>1970 – major revision – more demanding standards, but somewhat relaxed enforcement through the 1980s<br><br>1990 – expanded to cover air-quality standards, motor vehicle emissions and **alternative fuels**, toxic air pollutants, acid rain, & stratospheric ozone depletion. | 1990 revision addresses specific emissions for heavy duty trucks and light duty vehicles<br>- Trucks – NOx $\leq$ 4 grams/bh hour<br>- All<br>- Vapor recovery systems required<br>  - 100% of sales by 1996<br>  - 95% capture rate<br>- CO and Hydrocarbons<br>  - 15 grams/mile for CO<br>  - 1.5 grams for hydrocarbons<br>  - Both reduced by 90% over 1981 lvl<br>- NOx after 1980 – 2 grams/mile<br>- NOx after 1981 – 1 gram/mile<br>- After 1993 reductions of all emissions<br>  - 1994 – 40%<br>  - 1995 – 80%<br>  - 1996 – 100%<br>NOTE: waivers can be granted by Dir. EPA |
| President's Hydrogen Initiative 2003 [6] | Intended to reduce dependence on foreign oil – become hydrogen fuel-based economy, and use hydrogen fueled cars | - Established Hydrogen Technical Advisory Committee<br>- **Hydrogen can be a key element in syngas production**<br>- In 2009 President Obama has reduced funding for hydrogen and fuel cell research and development from approx $169M to approx. $69M |

**Table 14. Federal Initiatives/Requirements *(Cont'd)***

| | | |
|---|---|---|
| Energy Policy Act – 2005 [7] | 1. Clean Coal – includes **gasification**<br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br><br>2. Fossil energy | 1. By 2020 have projects able to<br>- Remove at least 97% of sulfur dioxide<br>- Emit no more than .08 lbs of NOx per million BTUs<br>- At least 90% reductions in mercury emissions<br>- Achieve increased thermal efficiencies by coal Btu content<br>- 43% for 9000 Btu<br>- 41% for 7,000 to 9,000 Btu<br>- 39% for less than 7,000 Btu<br>For **gasification projects** calls for tighter requirements<br>- Remove at least 99% of sulfur dioxide<br>- Emit no more than .05 lbs of NOx per million BTUs<br>- At least 95% reduction in mercury emissions<br>- Achieve increased thermal efficiencies, by coal Btu content<br>- 50% for 9,000 Btu<br>- 48% for 7,000 to 9,000 Btu<br>- 46% for less than 7,000 Btu<br>In all cases, **carbon capture** is stressed and above 50% capture, efficiencies are credited/energy used not counted<br>2. Sets criteria/focus for funding projects, including:<br>**- Gasification systems**<br>**- Turbines for syngas from coal**<br>**- Carbon Capture & Sequestration**<br>**- Coal-derived chemicals and transportation fuels**<br>**- Solid fuels and feed-stocks**<br>**- Advanced coal research**<br>**Calls for increased R&D in carbon capture and sequestration.**<br>- Provides CCS R&D funds<br>- FY 2006 - $25M<br>- FY 2007 - $30M<br>- FY 2008 - $35M |
| President's Advanced Energy Initiative [8] | Focused on vehicles and homes/offices. References specifics in the 2005 Energy Policy Act | Provides for funding to support various areas covered in the 2005 Energy Policy Act |

**Table 14. Federal Initiatives/Requirements *(Cont'd)***

| | | |
|---|---|---|
| Energy Independence and Security Act of 2007 [9] | 1. Corporate Average Fuel Economy Standards (CAFÉ) | 1. Set CAFE standards:<br>- Combined fleet of cars and light trucks by model – 35 mpg by 2020<br>- Interim standards starting in 2011<br>- Must meet 92% of standard each year<br>- Can apply "credits" between models |
| | 2. Renewable Fuel Standard (RFS) – deals with minimum annual use of renewable fuels | 2. RFS looks at:<br>- **Usage quantity levels**<br>**- Increased level from 5.4B gals for 2008 to 7.5B gals by 2012, and to 36B gals by 2022.**<br>**- Sources of fuels**<br>- **Starting in 2016 all RFS increase must come from advanced biofuel.**<br>**- Special carve-outs for**<br>**- Cellulosic biofuels**<br>**- Biomass based diesel**<br>**- Green House Gases**<br>- **Renewable fuels from new biorefineries must reduce GHG by at least 20% life cycle GHGs over GHGs from conventional gasoline and diesel** |
| | 3. Procurement and acquisition of alternative fuels | 3. Section 526 essentially states that no Federal agency shall contract for any alternative or synthetic fuel unless that fuel has life cycle GHG emissions equal to or less than the GHG emissions from convention fuels. |
| America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act. Signed into law on 9 August 2007 [10] | Created basis for formation of the Advanced Research Projects Agency – Energy (ARPA-E) | - Extended the Energy Policy Act of 2005 and provided funding of $5.8B through 2010 for DOE basic research.<br>- Establishes a Director of ARPA-E within the DOE.<br>- Provides for personnel within the ARPA-E of 70 to 120<br>- Provides funding of $300M for 2008, 2009, and 2010.<br>- ARPA-E budget is separate from the overall DOE budget. |

Both the cost of complying with established emissions levels and the availability and maturity of technology to achieve the levels must be considered. For example, one way proposed to deal with increased $CO_2$ generated by the Fischer-Tropsch process is carbon capture and sequestration (CCS). The CCS approach captures the carbon dioxide and pumps it into underground holding areas. The Department of Energy is currently conducting studies of CCS approaches.

There continue to be a multitude of proposed requirements coming from both houses of Congress.[11] This landscape changes on an almost daily basis. Table 15 provides a summary of some of the latest initiatives regarding cap-and-trade. Table 16 provides summary details on other federal legislative proposals.[12]

**Table 15. Greenhouse Gas Cap-And-Trade Proposal Reduction Targets in the 110th Congress**

| Bill | 2010–2019 Cap | 2020–2029 Cap | 2030–2050 Cap |
|---|---|---|---|
| **Boxer-Lieberman-Warner**<br>S. 3036 – June 2008<br>Lieberman-Warner Climate Security Act of 2008<br>Substitute ammendment to S. 2191 considered by full Senate | 4% below 2005 level in 2012 | 19% below 2005 level in 2020 | 37% below 2005 level in 2030<br>55% below 2005 level in 2040<br>71% below 2005 level in 2050 |
| **Bingaman-Specter**<br>S. 1766 – July 2007<br>Low Carbon Economy Act | Start at 2012 level in 2012 | 2006 level in 2020 | 1990 level in 2030<br>President may set long-term target ≥60% below 2006 level by 2050 contingent upon international effort |
| **Kerry-Snowe**<br>S. 485 – February 2007<br>Global Warming Reduction Act | Start at 2010 level in 2010 | 1990 level in 2020<br>2.5%/year reduction from 2020-2029 | 3.5%/year reduction from 2030-2050<br>62% below 1990 level in 2050 |
| **Sanders-Boxer**<br>S. 309 – January 2007<br>Global Warming Pollution Reduction Act | Start at 2010 level in 2010<br>2%/year reduction from 2010-2020 | 1990 level in 2020 | 27% below 1990 level in 2030<br>53% below 1990 level in 2040<br>80% below 1990 level in 2050 |
| **McCain-Lieberman**<br>S. 280 – January 2007<br>Climate Stewardship and Innovation Act | 2004 level in 2012 | 1990 level in 2020 | 20% below 1990 level in 2030<br>60% below 1990 level in 2050 |
| **Markey**<br>H.R. 6186 – June 2008<br>Investing in Climate Action and Protection Act | 2005 level in 2012 | 20% below 2005 levels in 2020 | 85% below 2005 levels in 2050 |
| **Waxman**<br>H.R. 1590 – March 2007<br>Safe Climate Act of 2007 | 2009 level in 2010<br>2%/year reduction from 2011-2020 | 5%/year reduction from 2020-2029 | 5%/year reduction from 2030-2050<br>80% below 1990 levels in 2050 |
| **Olver-Gilchrest**<br>H.R. 620 – January 2007<br>Climate Stewardship Act | 2005 level in 2012 | 1990 level in 2020<br>1990 level in 2020 | 22% below 1990 level in 2030<br>70% below 1990 level in 2050 |

Source: Pew Center on Global Climate Change, http://www.pewclimate.org/docUploads/Cap-and-Trade-Chart.pdf

**Table 16. Federal Legislative Proposals**

# Federal Legislative Proposals

| Bill | S. 2191 – America's Climate Security Act of 2007 (Lieberman) | S. 1766 – Low Carbon Economy Act of 2007 (Bingaman) | S. 317 – Electric Utility Cap and Trade Act of 2007 (Feinstein) | S. 485 – Global Warming Pollution Reduction Act of 2007 (Kerry) |
|---|---|---|---|---|
| General Provisions | Requires EPA to establish a GHG registry and a GHG emissions allowance transfer system for covered facilities, including specified facilities within the electric power and industrial sectors and facilities that produce or entities that import petroleum- or coal-based transportation fuel or chemicals. | Would require that specified regulated entities (including certain fuel distributors and owners and operators of coal facilities or nonfuel regulated entities) to submit to the President: (1) the number of allowances or credits equal to the entity's covered GHG emissions; or (2) a payment equal to the amount of the technology accelerator payment price in lieu of submission of required allowances. | Would amend the Clean Air Act to require EPA to establish an allowance trading program to address GHG emissions from electric generating facilities that: (1) have a nameplate capacity greater than 25 megawatts; (2) combust GHG emitting fuels; and (3) generate electricity for sale. The bill also would provide for annual tonnage limitations for GHG emissions from such facilities for 2011-2020. | The bill would amend the Clean Air Act to direct EPA to: (1) promulgate regulations necessary to reduce the aggregate net level of global warming pollution emissions; and (2) establish a market-based emissions cap and global warming pollutants trading program. The bill also would require EPA to: (1) establish, and revise every five years, standards for passenger vehicle emissions; and (2) research global climate change standards and processes. |
| Cap and trade? | Would establish emission allowances for 2012-2050, with a declining cap on GHGs, and would provide for selling, exchanging, transferring, submitting, retiring, or borrowing emission allowances. | The bill also would require the President to establish a trading system for such allowances and credits. | Yes | Yes |
| Emission Reduction Targets | By 2012: 5,200 million tons.<br>By 2020: 4,432 million tons.<br>By 2030: 3,472 million tons. | By 2012: 6.652 million tons.<br>By 2030: 4,819 million tons (1990 levels). | By 2014: 2006 levels.<br>By 2015: 2001 levels.<br>By 2019: reduce 1% per year. | By 2020: 1990 levels.<br>By 2030: 22% below 1990 levels.<br>Reduce 3.5% per year until 2050. |

**Table 16. Federal Legislative Proposals *(Cont'd)***

| Bill | S. 309 – Global Warming Pollution Prevention Act (Boxer) | H.R. 620 – Climate Stewardship Act of 2007 (Olver) | H.R. 1590 – Safe Climate Act of 2007 (Waxman) | H.R. 4226 – Climate Stewardship and Economic Security Act of 2007 (Gilchrest) |
|---|---|---|---|---|
| General Provisions | The bill would amend the Clean Air Act to set forth provisions concerning global warming pollution emissions. EPA would be required to: (1) set milestones to reduce the aggregate net levels of emissions; (2) require each fleet of automobiles sold by a manufacturer beginning in model year 2016 to meet emission standards; (3) contract with the National Academy of Sciences to study the potential contribution of the non-highway portion of the transportation sector towards meeting the emission reduction goal; (4) require that electric generation units meet an emission standard that is not higher than the emission rate of a new combined cycle natural gas generating unit; and (5) establish a low-carbon generation trading program. | Would require the EPA to establish a National Greenhouse Gas Database consisting of: (1) an inventory of GHG emissions by covered entities (specified entities that own or control a source of GHG emissions in the electric power, industrial, and commercial sectors of the U.S. economy that emit more than 10,000 metric tons of GHGs per year); and (2) a registry of GHG emission reductions and increased sequestration, applicable to both covered and noncovered entities. | This bill would amend the Clean Air Act to direct EPA to promulgate: (1) targets for a 2 percent reduction in GHG emissions each year from 2010-2050; and (2) regulations requiring reductions to meet such targets, including by setting caps on emissions of sources and sectors with the largest emissions or the best opportunities to reduce them, by issuing and authorizing trading of emission allowances, and by imposing penalties for excess emissions. The bill would require relevant federal agencies to finalize a rule to carry out the National Academies' recommendations for regulatory action needed to reduce atmospheric GHG concentrations or explain their reasons for declining to act. | Would require EPA to establish a National Greenhouse Gas Database consisting of: (1) an inventory of GHG emissions by covered entities (specified entities that own or control a source of GHG emissions in the electric power, industrial, and commercial sectors of the U.S. economy that emit more than 10,000 metric tons of GHGs per year); and (2) a registry of GHG emission reductions and increased sequestration, applicable to all entities. EPA's Administrator would be required to establish a declining cap on allowances to reduce GHG emissions over time. Beginning in 2012, covered entities would be required to submit to EPA one allowance for every metric ton of GHGs emitted. |
| Cap and trade? | EPA may establish one or more market-based emission reduction programs. | The bill would establish a program for the market-driven reduction of GHGs by covered entities through the use of tradeable emissions allowances. | Yes | The bill also establishes a program for the market-driven reduction of GHGs by covered entities through the use of tradeable emissions allowances. |
| Emission Reduction Targets | By 2020: reach 1990 emission levels.<br>By 2030: reduce by 1/3 of 80 percent of the aggregate net level of global warming pollution emissions of the U.S. during calendar year 1990. | By 2012: 6,150 million tons.<br>By 2020: 5,232 million tons.<br>By 2030: 3,858 million tons. | By 2010: 2009 levels.<br>By 2019: reduce by 2% per year.<br>By 2020: 1990 levels.<br>By 2050: 80% below 1990 levels. | 2011-2019: tradeable allowances equal to the number of metric tons of GHGs emitted in 2006.<br>2019-2029: 85 percent of 2006 levels.<br>2029-2039: 63 percent of 2006 levels. |

All information from http://thomas.loc.gov

State and Local Level – many states have taken action to form associations, coalitions, and study groups to address emissions in their state. In addition, several states have enacted policies and/or legislation aimed at reducing emission levels. Table 17 provides details. [13]

**Table 17. State & Regional Emission Reduction Targets**

| Entity/Scope | Targets and Timetables |
| --- | --- |
| Arizona: State-wide | 2000 levels by 2020; 50% below 2000 by 2040 |
| California: State-wide | 2000 levels by 2010; 1990 levels by 2020; 80% below 1990 by 2050 |
| Connecticut: State-wide | 1990 levels by 2010; 10% below 1990 by 2020; 80% below 2001 levels by 2050 |
| Florida: State-wide | 2000 levels by 2017; 1990 levels by 2025; 80% below 1990 levels by 2050 |
| Hawaii: State-wide | 1990 levels by 2020 |
| Illinois: State-wide | 1990 levels by 2020; 60% below 1990 levels by 2050 |
| Maine: State-wide | 1990 levels by 2010; 10% below 1990 by 2020; 75-80% below 2003 long-term |
| Massachusetts: State-wide | 1990 levels by 2010; 10% below 1990 by 2020; 75-85% below 2001 long-term |
| Minnesota: State-wide | 15% below 2005 levels by 2015; 30% below 2005 levels by 2025; 80% below 2005 levels by 2050 |
| New Hampshire: State-wide | 1990 levels by 2010; 10% below 1990 by 2020; 75-85% below 2001 long-term |
| New Jersey: State-wide | 1990 levels by 2020; 80% below 2006 levels by 2050 |
| New Mexico: State-wide | 2000 levels by 2012; 10% below 2000 by 2020; 75% below 2000 by 2050 |
| New York: State-wide | 5% below 1990 by 2010; 10% below 1990 by 2020 |
| Oregon: State-wide | Stabilize by 2010; 10% below 1990 by 2020; 75% below 1990 by 2050 |
| Rhode Island: State-wide | 1990 levels by 2010; 10% below 1990 by 2020; 75-85% below 2001 long-term |
| Utah: State-wide | 2005 levels by 2020 |
| Vermont: State-wide | 1990 levels by 2010; 10% below 1990 by 2020; 75-85% below 2001 long-term |
| Virginia: State-wide | 30% below business as usual by 2025 |
| Washington: State-wide | 1990 levels by 2020; 25% below 1990 levels by 2035; 50% below 1990 levels by 2050 |
| New England Governors and Eastern Canadian Premiers: Regional economy-wide | 1990 levels by 2010; 10% below 1990 by 2020 |
| Regional Greenhouse Gas Initiative: $CO_2$ emissions from power plants | Cap emissions at current levels in 2009; reduce emissions 10% by 2019 |
| Western Climate Initiative | 15% below 2005 levels by 2020 |

Source: Pew Center on Global Climate Change, http://www.pewclimate.org/states-regions

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# APPENDIX A

## The Chemistry of Converting Non-Petroleum-Based Materials to Liquid Fuel

What follows is a description of the basic processes and chemistry associated with the conversion of non-petroleum materials to liquid fuels, referred to herein as synthetic fuels and biofuels. There are a significant number of variables that affect the multiple elements of these processes. These range from the specific material to be converted (such as coal), its caloric value, the liquefaction approach used, the type of catalyst used in a reactor (such as a Fischer-Tropsch reactor), to the type of reactor itself. What is presented here is representative of the various non-petroleum materials to liquid fuel processes. The discussion is relatively basic, and is further restricted to those materials and associated conversion processes that are proven and to some extent are in use today. The entire synthetic fuel arena is extremely dynamic and changes almost daily. The reader is referred to the various sources cited for more in-depth details and discussions.

Creation of synthetic fuel is basically the process of converting a carbonaceous material to another form. Converting carbonaceous material is the process of hydrogenation, or the addition of hydrogen to the raw material. (NOTE: conversion can also be accomplished using a carbonization process, discussed below under “direct liquefaction.) The carbonaceous materials discussed below are coal, methane, ethanol, and biomass.

**Coal -** One of the most abundant carbonaceous materials in the United States is coal. The conversion of coal to liquid fuel is accomplished using one of three proven methods: 1) Indirect Liquefaction involving the Fischer-Tropsch (F-T) process; 2) Direct Liquefaction; and 3) Pyrolysis.[1]

Indirect Liquefaction Fischer-Tropsch involves four basic steps, as shown in the following diagram:

Gasification → Gas Purification → Fischer Tropsch Synthesis → Product Upgrading

Gasification - during gasification, the coal is subjected to high temperature in the presence of oxygen and steam. The basic chemistry for the gasification of coal, using steam and oxygen is:

$$\begin{array}{ccc} \text{Input} & & \text{Output} \\ \text{Coal } H_2O, O_2 & \longrightarrow & CO, H_2, N_2, CO_2, H_2S, NH_3 \end{array}$$

On the input side, a significant amount of water is required as the source of the hydrogen. Water requirements must be taken into account when considering a location for an FTS plant.

Within the gasifier there are three thermal and chemical processes that occur:

- Pyrolysis - chemical breakdown of complex compounds
- Oxidation – controlled burning
- Reduction – reactions that produce an output of carbon dioxide, hydrogen, and methane.[2]

The output of this process is called synthetic gas, or more commonly syngas. Syngas consists mainly of hydrogen and carbon monoxide. (NOTE: Syngas can be used to produce liquid fuels as discussed here, as well as synthetic natural gas, hydrogen, and other useful products.) Syngas

can also contain a variety of elements that are considered impurities with regard to use of the syngas in the Fischer-Tropsch Synthesis (FTS) process. The types and amounts of impurities are related to the type of coal used as feed stock to the gasification process. The most common impurities are sulfur and nitrogen, which are converted during the gasification process to hydrogen sulfide ($H_2S$) and ammonia ($NH_3$) respectively.[3] These impurities need to be reduced or eliminated through gas purification, as they impact the effectiveness and efficiency of the FTS process.

NOTE: The discussion thus far has dealt with gasification of coal in a reactor vessel. Coal can also be gasified in situ, in seams that are not reachable using conventional mining techniques. In simple terms, wells are drilled into the coal seam and oxidants are injected and used to ignite the coal. Another well is drilled to extract the resulting syngas, which typically consists of carbon monoxide (CO), hydrogen ($H_2$), carbon dioxide ($CO_2$), and small quantities of methane ($CH_4$) and hydrogen sulfide ($H_2S$).[4]

Gas purification - The syngas is processed further to reduce or remove the following impurities:

- Nitrogen Gas ($N_2$)
- Carbon Dioxide ($CO_2$)
- Hydrogen Sulfide ($H_2S$)
- Ammonia ($NH_3$)

Note: the four constituents listed are those that are detrimental to the Fischer-Tropsch phase. Other impurities are also generated, in trace amounts, that are of an environmental concern. These include arsenic, lead, silver, and mercury. These are most often found in the processing water and/or other solid residues and must also be properly processed/disposed of to avoid environmental contamination.

Use of a water wash is effective in removing the ammonia which is very soluble in water.[5] More problematic is the removal of the hydrogen sulfide. Two primary methods used are the direct conversion process (sulfur recovery) or indirect conversion process (acid gas removal). Both use liquid absorbent, which is effective in removing both hydrogen sulfide and carbon dioxide. The indirect process is the most common. One example is the Lurgi patented Rectisol Process, which uses cold methanol as the liquid absorbent.[6]

Fischer Tropsch Synthesis (FTS) - The F-T process exposes purified syngas to a catalyst under controlled temperature and pressure conditions to produce aliphatic hydrocarbons. Basically, the process takes place in a reactor. In the case of the raw synthetic liquid which is produced, that output is then fractioned (refined) to produce diesel, gasoline, industrial gas (methane), and other hydrocarbons. Figure A-1 is a simplified diagram of the FTS process as it is used by a company called Sasol.[7]

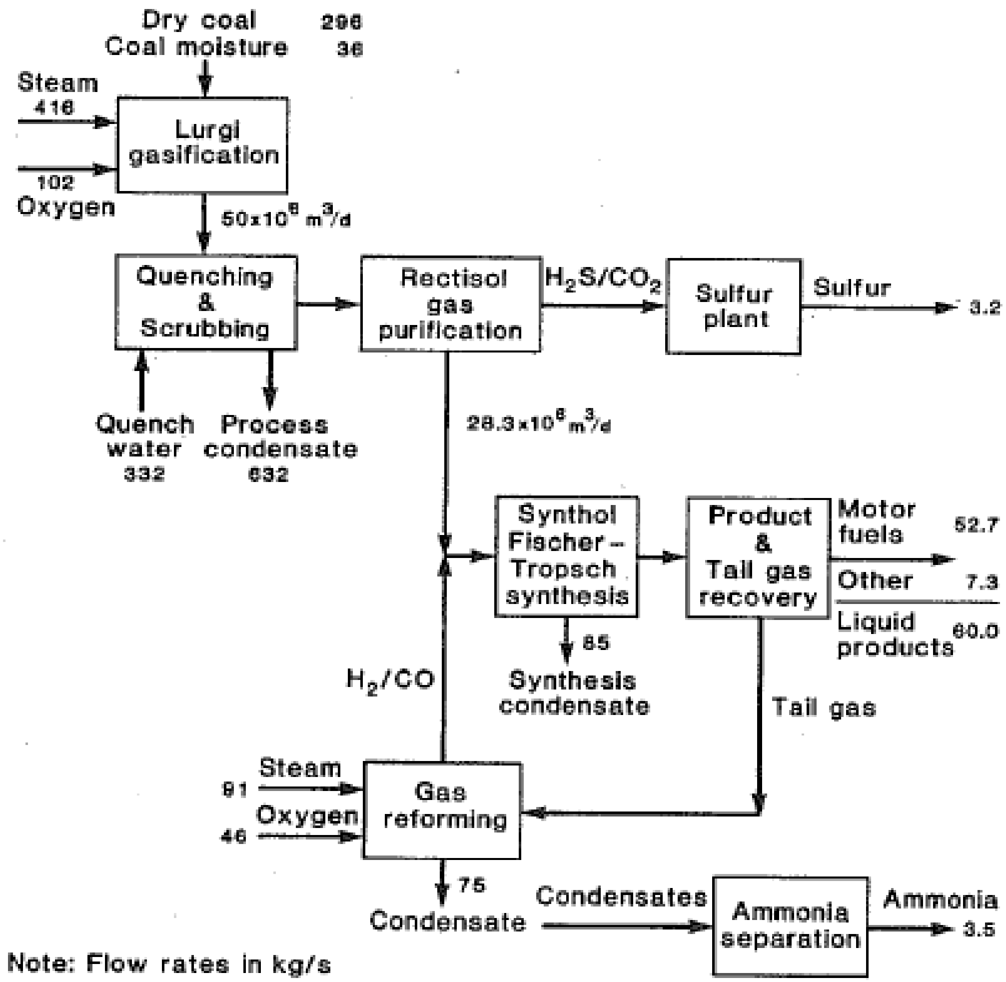



**Figure A-1.**

The block labeled "Synthol Fischer-Tropsch synthesis" in Figure A-1 represents the FTS reactor. The Syntrol reactor uses iron (FE) as the catalyst. The other common catalyst is cobalt (CO).

The ideal stoichiometry for FTS reaction is:

$$CO + 2H_2 \longrightarrow (\text{--}CH_2\text{--}) + H_2O$$

There are several types of FTS reactors, some of which have been developed by companies with extensive experience in the CTL process. Each reactor has features designed to deal with specific aspects of conversion of syngas to various hydrocarbons.

Fundamentally the reaction of the catalyst with the carbon monoxide and the hydrogen results in generation of a variety of hydrocarbons that can be captured and processed further or directly used, depending on the characteristics of the substance. Representative constituents for FTS reactions in a Synthol entrained reactor, expressed in terms of percent of the total mass of the constituents, are shown in Table A-1.[8]

**Table A-1.**

| Constituent | Molar Formula | Mass % |
|---|---|---|
| **Gases** | | |
| • Methane | $CH_4$ | 11 |
| • Ethene | $C_2H_4$ | 4 |
| • Ethane | $C_2H_6$ | 6 |
| • Propene | $C_3H_6$ | 11 |
| • Propane | $C_3H_8$ | 2 |
| • Butene | $C_4H_8$ | 8 |
| **Liquids** | | |
| • $C_5 – C_7$ | $C_{5.5}H_{11}$ | 8 |
| • Light oils | $C_8H_{16}$ | 33 |
| • Heavy oils | $C_{20}H_{42}$ | 6 |
| • Alcohols | $C_{2.4}H_{6.8}O$ | 9 |
| • Acids | $C_{2.4}H_{4.8}O_2$ | 2 |
| | | 100% |

Specific FTS products are synthesized according to the following reactions:[9]

$CO + 3H_2 \longrightarrow CH_4 + H_2O$ (Methanation)

$nCO + (2n + 1)H_2 \longrightarrow C_nH_{2n+2} + nH_2O$ (Paraffins)

$nCO + 2nH_2 \longrightarrow C_nH_{2n} + nH_2O$ (Olefins)

$nCO + 2nH2 \longrightarrow C_nH_{2n+1}OH + (n-1) H_2O$ (Alcohols)

Product upgrade, the final step in the process, is the refraction of the various outputs into fuels and oils.

Direct Liquefaction is the process wherein coal is hydrogenated or carbonized. In hydrogenation, the coal is ground so it can be mixed into coal derived recycle solvent to form a coal-oil slurry feed. The slurry containing 30-50% coal is then heated to between 420 - 450$^o$C in a hydrogen atmosphere under high pressure (200-300 bars). The liquids produced require further refining to produce usable fuels.[10] In carbonization using the Low Temperature Carbonization (LTC) process, coal is coked at temperatures between 450 and 700$^o$C (lower than temperatures used in the normal coking process, which is a carbonization approach producing coke for metallurgic applications), producing a very high carbon content char as well as various gases.

The fundamental hydrogenation process was developed by Friedrick Bergius in 1913. His process includes a small amount of molybdenum (approx 1% by weight) acting as a catalyst. This process yields synthetic crude, naphtha, and light weight liquids ($C_5$-$C_{10}$) suitable for use as fuels, as well as a significant amount of carbon dioxide. The overall reaction for direct liquefaction using hydrogenation is summarized as:[11]

$${}_nC + (n+1)H_2 \longrightarrow C_nH_{2n+2}$$

Figure A-2 represents the primary steps and flow of the direct liquefaction process using hydrogenation.[12]

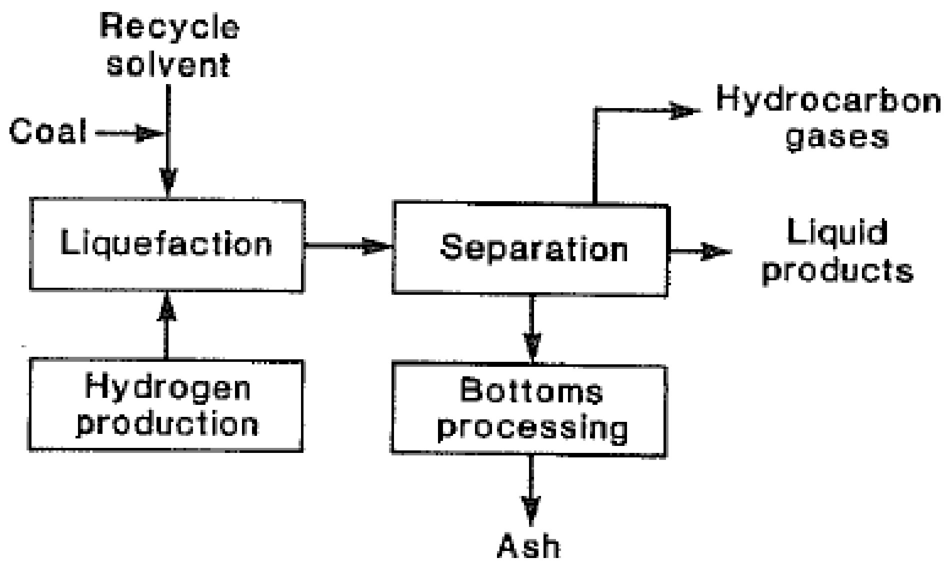



**Figure A-2.**

The Low Temperature Carbonization (LTC) process is called the Karrick process. Lewis C. Karrick refined the process to what it is today. Multiple patents were filed in the 1931 - 1942 time period but have since expired. Extensive research was unable to find an expression of the chemical actions that take place in the carbonization process.

Figure A-3 represents the equipment layout in the direct liquefaction process using the LTC Karrick carbonization process.[13] This diagram is from one of Karrick's patents, U.S Patent #1,958,918.

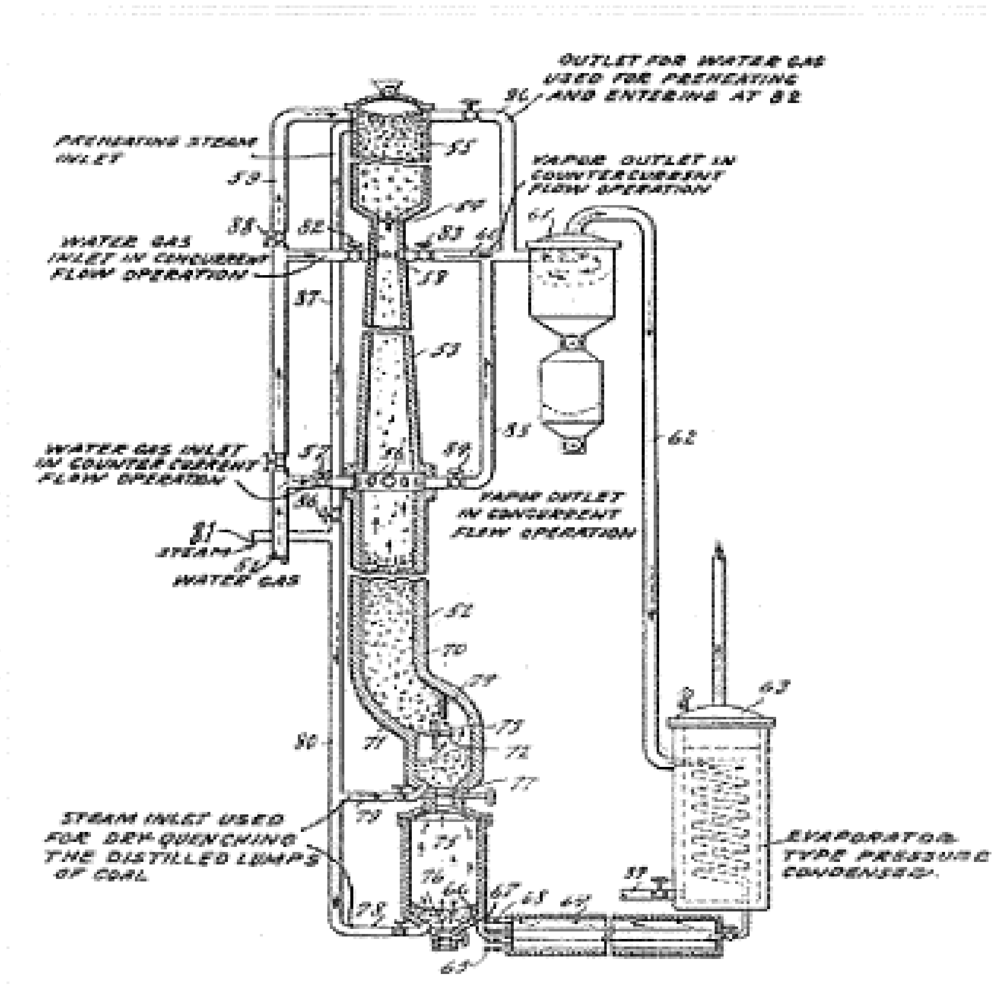



**Figure A-3.**

<u>Pyrolysis</u> is defined as the chemical decomposition of a condensed substance by heating. The simplest example of pyrolysis is burning, or the exposure of substances to high temperatures under controlled conditions. It is most commonly used for organic materials, and consists of heating in a limited/controlled oxygen environment. In the synthetic fuels arena, Pyrolysis can be used with several feed-stocks, and can be the primary process or can be part of another overall process, such as in the gasification process described above. While one feed-stock is coal, pyrolysis is more commonly used with oil shale, tar sands and biomass feed-stocks.[14] Figure A-4 shows the basic steps in pyrolysis that produces synthetic fuel.[15]

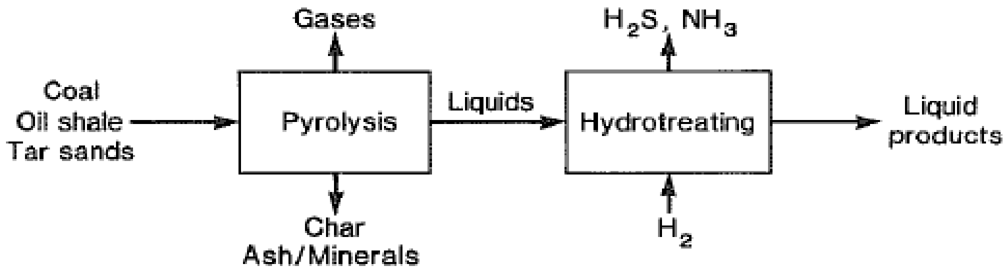
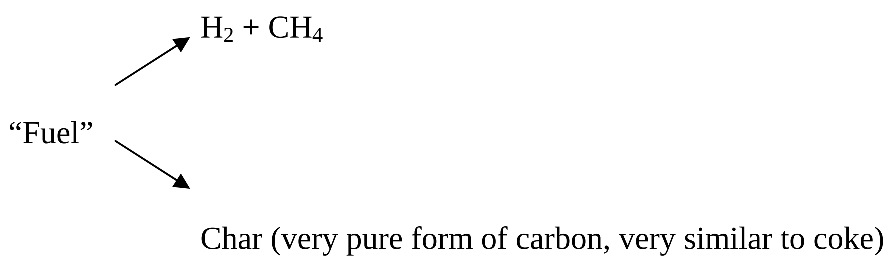



**Figure A-4.**

The exact nature of what occurs in the pyrolysis of coal is subject to continued analysis and is not fully understood. What is known is that the composition of the raw material, the temperature and the rate of heating (slow vs. rapid) all affect both the amount and composition of the volatile yields.[16] Again, recall that in the gasification process discussed above, pyrolysis is one of three actions that take place in the gasification reactor. A simplified representation of what occurs in the pyrolysis process is shown below. The “fuel” may be any number of carbonaceous materials ranging from coal to biomass. The two basic results are the gases and the char.




Pyrolysis is used extensively in the chemical industry to produce, for example, charcoal, activated carbon, methanol, and other chemicals from wood, to convert biomass to syngas, and for the cracking of medium weight hydrocarbons from oil to produce lighter ones like gasoline.

There are several process approaches for accomplishing pyrolysis of coal in the market today. Table A-2 provides comparative yield information for the major processes. Note the maturation status (as of the writing of the reference source, 1982). The type of coal used is also cited.[17]

**Table A-2.**

| Process | Status | Coal* | Yield, mass % dry coal | | | |
|---|---|---|---|---|---|---|
| | | | Char | Tar/Oil | Gas | Water |
| COED, FMC Corporation | Developed | Bit. | 62 | 21 | 14 | 3 |
| TOSCOAL | Developed | Subbit. | 69 | 13 | 9 | 9 |
| Lurgi-Ruhrgas | Commercial | Subbit. | 50 | 32** | 11 | 7** |
| Occidental Flask Pyrolysis | Developing | Bit. | 56 | 35 | 7 | 2 |
| Rockwell/Cities Service Flash Hydropyrolysis | Developing | Bit. | 46 | 38 | 16 | - |
| Supercritical Gas Extraction, NCB | Developing | Bit. | 63 | 33*** | 2 | 2 |

* Bit. – Bituminous; Subbit. – Sub bituminous

** Water plus tar/oil sum 39%, individual values estimated

*** Tar extract, softening point 70$^{o}$C.

**Methane -** Methane is the principle component of natural gas, about 87% by volume. The earth's crust contains huge amounts of methane, and the gas is also produced by several natural actions, to include animals (primarily cows) through enteric fermentation in their digestive systems. Decaying organic wastes in solid waste landfills also generates a significant quantity of methane. In the chemical industry, methane is the feedstock of choice for production of hydrogen, methanol, acetic acid, and acetic anhydride.

Methanol Synthesis utilizes methane gas to create methanol. The process starts with generation of syngas by steam reforming, using a nickel catalyst at high temperature (700-1100$^o$C). The process is represented by:[18]

$$CH_4 + H_2O \xrightarrow[700\text{-}1100^oC]{Ni} CO + 3H_2$$

German chemists Alwin Mittasch and Mathias Pier developed a method to convert syngas, most often produced from coal or natural gas or from use of biomass feedstock, into methanol. This process used a chromium and manganese oxide catalyst and was conducted under pressures ranging from 50 to 220 atmospheres and temperatures up to 450$^o$C. The process has since been refined so that today it involves a catalyst mixture of copper, zinc oxide, and alumina (first used by ICI) and much lower pressure. The Low Pressure Methanol (LPM) process was developed by ICI in the late 1960s. Figure A-5 shows a simplified representation of LPM synthesis.[19]

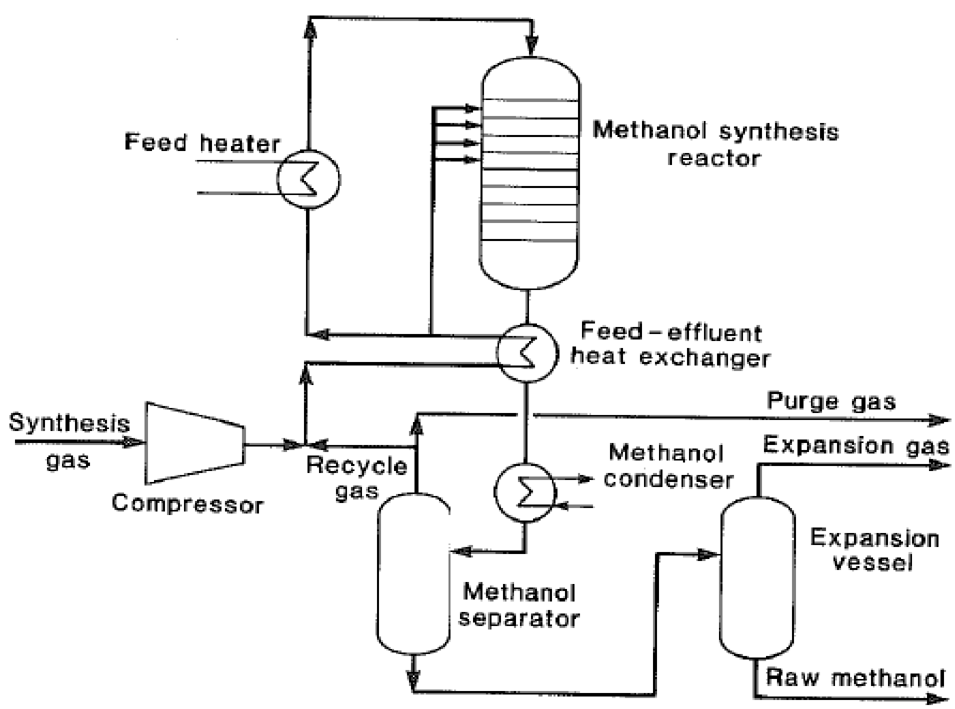



**Figure A-5.**

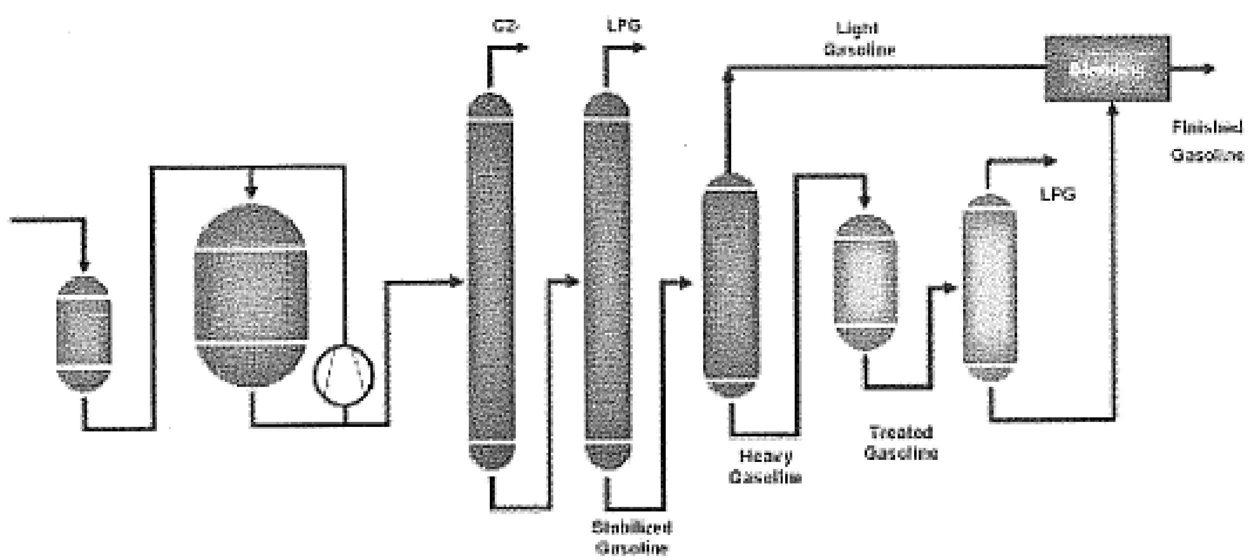
The chemical action taking place in the Methanol Synthesis reactor to produce the methanol involves the aforementioned copper, zinc oxide, and alumina catalyst and is represented by:[20]

$$CO + 2H_2 \longrightarrow CH_3OH$$

$$CO_2 + 3H_3 \longrightarrow C\ H_3OH + H_2O$$

Methanol is currently used to fuel internal combustion engines in applications where it is safer than gasoline because methanol is not as flammable as gasoline.

In the early 1970s, a Methanol to gasoline (MTG) process was developed by Mobil. The MTG process produces a single output consisting of a very low sulfur, low benzene, high quality gasoline. The methanol can be generated from natural gas reforming, coal gasification, or biomass conversion. The methanol is first dehydrated to dimethylether (DME). The equilibrium mixture of methanol, DME, and water is then converted to light olefins ($C_2 – C_4$). A final reaction step leads to a mixture of higher olefins, n/iso-paraffins, aromatics, and naphthenes. Interrupting the reaction would lead to production of light olefins instead of gasoline. Figure A-6 provides a layout of the Mobil MTG process.[21]




DME Reactor MTG Reactor DeEthanizer Stabilizer Splitter HGT Reactor

Compressor Stabilizer

**Figure A-6.**

A very simplified expression of the chemistry involved in the Mobil MTG process is:[22]

$$2CH_3OH \longrightarrow CH_3OCH_3 + H_2O \longrightarrow$$

$$\text{Light Olefins} + H_2O \longrightarrow \text{Higher Olefins}$$

$$+ \text{Aromatics} + \text{Naphthenes}$$

A comparison of the constituents resulting from use of the FTS process, shown for both the low temperature (428$^o$ F) iron and the high temperature (644$^o$ F) cobalt catalyst results, and the Mobil MTG process is provided in Table A-3. Figures are percent by weight.[23]

**Table A-3.**

| | Low temp FTS – CO catalyst | High temp FTS – iron catalyst | MTG |
|---|---|---|---|
| **Methane** | 5 | 8 | 0.7 |
| **Ethylene** | 0 | 4 | - |
| **Ethane** | 1 | 3 | 0.4 |
| **Propylene** | 2 | 11 | 0.2 |
| **Propane** | 1 | 2 | 4.3 |
| **Butylenes** | 2 | 9 | 1.1 |
| **Butane** | 1 | 1 | 10.9 |
| **$C_5$ – 160C** | 19 | 36 | 82.3 |
| **Distillate** | 22 | 16 | - |
| **Heavy oil/wax** | 46 | 5 | - |
| **Water soluble oxygenates** | 1 | 5 | 0.1 |
| **Total** | 100 | 100 | 100 |

**Ethanol –** ethanol (also called ethyl alcohol, pure alcohol, grain alcohol, or drinking alcohol) is a volatile, flammable, colorless liquid. Ethanol can be produced through the hydration of ethylene, or biologically by the action of microorganisms and enzymes through the fermentation of sugars or starches, or cellulos, part of ligncellulosic matter. The output is referred to as bioethanol, and will be the focus of the discussion here.[24]

In the U.S., the starch-based feedstock of choice for production of ethanol has predominately been corn. In some areas of the country, sorghum has also been successfully used. Other crop type sources include wheat, sugar beets, sugar cane, molasses, or any sugar or starch that alcoholic beverages can be made from (e.g., potatoes, fruit wastes, etc.). For starchy materials, the starch must be converted into sugars in order for fermentation to then be accomplished.[25]

The two established processes using corn are the dry milling and the wet milling methods. The primary difference is in the initial preparation and processing of the grain prior to fermentation. Corn supply is limited when compared to all other ligncellulosic materials. Corn has value as food whereas sources of ligncellulosic materials may not have as high an intrinsic value.[26]

Lignocellulose is a structural material that comprises much of the mass of plants.

Sources of lignocellulosic materials are extensive, and typically include corn stover, switchgrass, miscanthus, woodchips, and the by products of lawn and tree maintenance. The primary process of creating ethanol from lignocellulosic material is by fermentation. In order for fermentation to take place, the lignocellulosic material must be processed and broken down to allow for separation of the glucose or simple sugars. Once the sugars are available, microbial fermentation of the sugar solution is accomplished followed by distillation to produce 99.5% pure alcohol. One glucose molecule is converted into two ethanol molecules and two carbon dioxide molecules.

The chemical equation that summarizes the fermentation of glucose is:[27]

$$C_6H_{12}O_6 \longrightarrow 2\,C_2H_5OH + 2\,CO_2$$

There are two approaches to producing ethanol from cellulose, both of which deal with the requirement to pre-treat the material in order to allow for release of the glucose required for the fermentation stage. The first is the Cellulosysis process, which is essentially a biological process. The second is gasification.

In the Cellulosysis process there are five stages:

- Pretreatment – used to release the cellulose from the lignin seal and its crystalline structure so the next step can be performed.
- Cellulose hydrolysis – breaks down the molecules into sugars. Can be done chemically, or enzymatically.
- Separation – separates the lignin from the sugar solution.
- Microbial fermentation of the sugar solution – complex due to the complex nature of the various hydrocarbons present in ligncellulosic biomass.
- Distillation – produces 99.5% pure alcohol.

The gasification process (also called the thermochemical approach), uses partial combustion to convert the raw carbon in the raw material into syngas. If ethanol is the desired output, then the syngas is fed into a special kind of fermenter which uses a microorganism called Clostridium Ljungdahlii, which will ingest the carbon monoxide, carbon dioxide, and hydrogen, and produce ethanol and water. The syngas can also be used in other established processes such as the FTS process to produce other desired fuels and related products.[28]

**Biomass** – biomass refers to renewable resources generally consisting of plant and animal waste. Biomass can come from many sources, including agriculture waste, animal waste, and industrial waste. One product that can be obtained from biomass is ethanol. A principle difference between cellulosic ethanol and biomass generated ethanol is that the cellulosic approach uses fermentation, whereas biomass uses a combustion process to achieve gasification. Fermentation does not convert all of the carbon compounds, which does occur in combustion. The combustion method applied to biomass essentially uses the pyrolysis process of causing the chemical decomposition of a condensed substance by heating in a limited/controlled oxygen environment. The outputs of the pyrolysis of biomass are charcoal, liquid fuels, and gaseous fuels.[29] The gas is called biogas, and differs from syngas, as reflected in the composition shown in Table A-4.[30]

**Table A-4.**

| | % v/v |
|---|---|
| Methane ($CH_4$) | 55-65 |
| Carbon Dioxide ($CO_2$) | 35-45 |
| Hydrogen Sulfide ($H_2S$) | 0-1 |
| Nitrogen ($N_2$) | 0-3 |
| Hydrogen ($H_2$) | 0-1 |
| Oxygen ($O_2$) | 0-2 |
| Ammonia ($N\,H_2$) | 0-1 |

Based on its high methane content, biogas is essentially a low grade natural gas. There are several ways to convert biomass into other forms of energy. One is combustion, but there is also thermochemical, biochemical, and chemical. Again, the process is intended to convert a

carbonaceous material, in this case biomass containing varying amounts of carbon, into another form. Biogas can be converted into gaseous fuels such as methane or hydrogen.[3]

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# APPENDIX B

## Biomass Collection and Biofuel Development

Today's quest for alternative fuel sources is driven more by Greenhouse Gas concerns than technical challenges. We have several domestic solutions that are constrained because they do not easily pass the environmental concern barrier. The several possible forms of fuel from biomass provide attractive solutions because of the carbon credits they bring to the Life Cycle Assessment of Greenhouse Gas footprints calculations.

The haunting problem of energy supply in general is the huge quantities our way of life demands. This quantity issue and the scale of source production involved is magnified in the biomass realm. The following table from NETL document, *Increasing Security and Reducing Emissions of the U.S. Transportation Sector: A Transformational Role for Coal with Biomass,* describes the challenges related to the implementation scale of various biomass candidates. The example used in Section 2.5, from this document considered a 7,500 barrel per day plant that co-fired 4,589 tons per day of Illinois # 6 coal and 510 tons per day of poplar. The following table shows the biomass production implications associated with producing this relatively small quantity of fuel. Remember that the Air Force objective to achieve a 50-50 (half synthetic and half traditional petroleum based fuel) blend of half of their domestic fuel requires 26,000 barrels per day.

**Table B-1. Estimated Collection Areas and Delivery Distances for Various Plant Sizes for Switchgrass, Poplar Trees, and Corn Stover**

| Feedstock | Biomass required (tons/day) | Biomass required (tons/year) | Conversion plant capacity factor | Biomass Storage and handling losses | Annual biomass demand (tons) | Yield (dry tons/ acre) | Total annual area required (acres) | Total annual area required (sq miles) | Percent land avail for production | Adjusted total area required (sq miles) | Harvest cycle (years) | Total area required for sustained operations (sq miles) | Distance, radius (miles) | Winding factor | Actual delivery distance (miles) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 500 | 182,500 | 90% | 10% | 180,675 | 6 | 30,113 | 47 | 8% | 588 | 1.25 | 735 | 15 | 1.3 | 20 |
| | 1,000 | 365,000 | 90% | 10% | 361,350 | 6 | 60,225 | 94 | 8% | 1,176 | 1.25 | 1,470 | 22 | 1.3 | 28 |
| | 1,500 | 547,500 | 90% | 10% | 542,025 | 6 | 90,338 | 141 | 8% | 1,764 | 1.25 | 2,206 | 26 | 1.3 | 34 |
| | 2,000 | 730,000 | 90% | 10% | 722,700 | 6 | 120,450 | 188 | 8% | 2,353 | 1.25 | 2,941 | 31 | 1.3 | 40 |
| Switchgrass | 2,500 | 912,500 | 90% | 10% | 903,375 | 6 | 150,563 | 235 | 8% | 2,941 | 1.25 | 3,676 | 34 | 1.3 | 44 |
| | | | | | | | | | | | | | | | |
| | 500 | 182,500 | 90% | 10% | 180,675 | 5 | 36,135 | 56 | 8% | 706 | 1 | 706 | 15 | 1.3 | 19 |
| | 1,000 | 365,000 | 90% | 10% | 361,350 | 5 | 72,270 | 113 | 8% | 1,412 | 1 | 1,412 | 21 | 1.3 | 28 |
| | 1,500 | 547,500 | 90% | 10% | 542,025 | 5 | 108,405 | 169 | 8% | 2,117 | 1 | 2,117 | 26 | 1.3 | 34 |
| | 2,000 | 730,000 | 90% | 10% | 722,700 | 5 | 144,540 | 226 | 8% | 2,823 | 1 | 2,823 | 30 | 1.3 | 39 |
| Poplar trees | 2,500 | 912,500 | 90% | 10% | 903,375 | 5 | 180,675 | 282 | 8% | 3,529 | 1 | 3,529 | 34 | 1.3 | 44 |
| | | | | | | | | | | | | | | | |
| | 500 | 182,500 | 90% | 10% | 180,675 | 1.98 | 91,250 | 143 | 31% | 460 | 1 | 460 | 12 | 1.3 | 16 |
| | 1,000 | 365,000 | 90% | 10% | 361,350 | 1.98 | 182,500 | 285 | 31% | 920 | 1 | 920 | 17 | 1.3 | 22 |
| | 1,500 | 547,500 | 90% | 10% | 542,025 | 1.98 | 273,750 | 428 | 31% | 1,380 | 1 | 1,380 | 21 | 1.3 | 27 |
| | 2,000 | 730,000 | 90% | 10% | 722,700 | 1.98 | 365,000 | 570 | 31% | 1,840 | 1 | 1,840 | 24 | 1.3 | 31 |
| Corn Stover | 2,500 | 912,500 | 90% | 10% | 903,375 | 1.98 | 456,250 | 713 | 31% | 2,300 | 1 | 2,300 | 27 | 1.3 | 35 |

The following set of CAFFI Roadmaps illustrates the concerted effort that organization has organized to develop and qualify a variety of biofuel candidates for aviation fuel use.

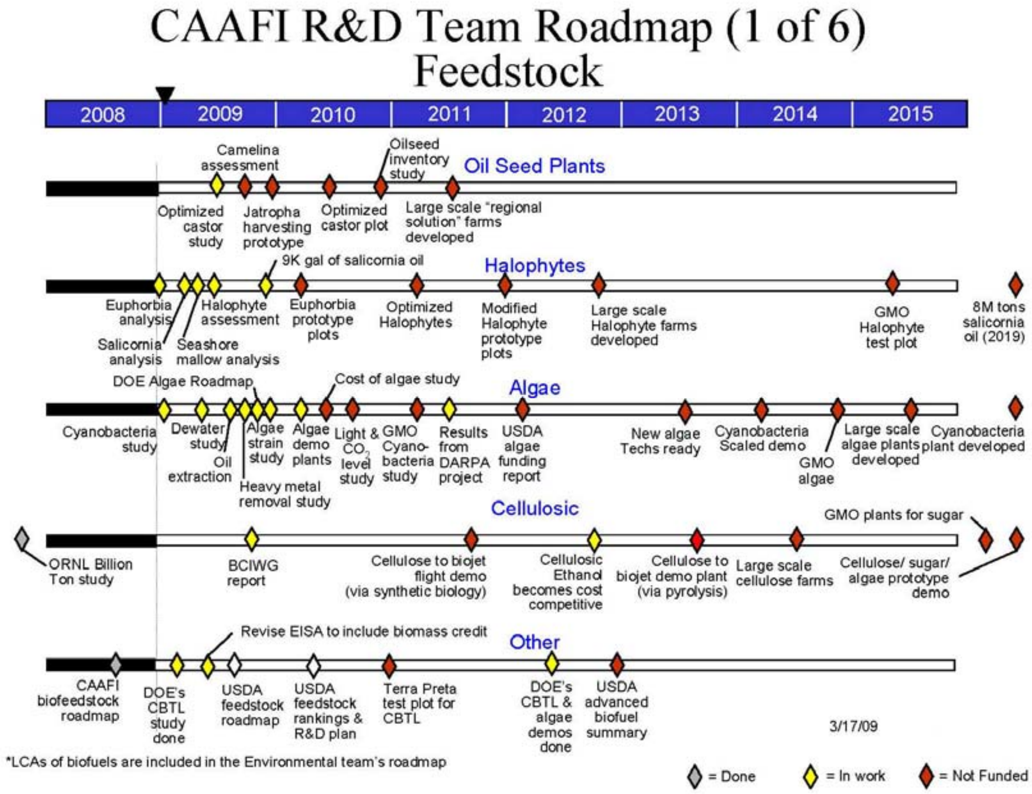



**Figure B-1.**

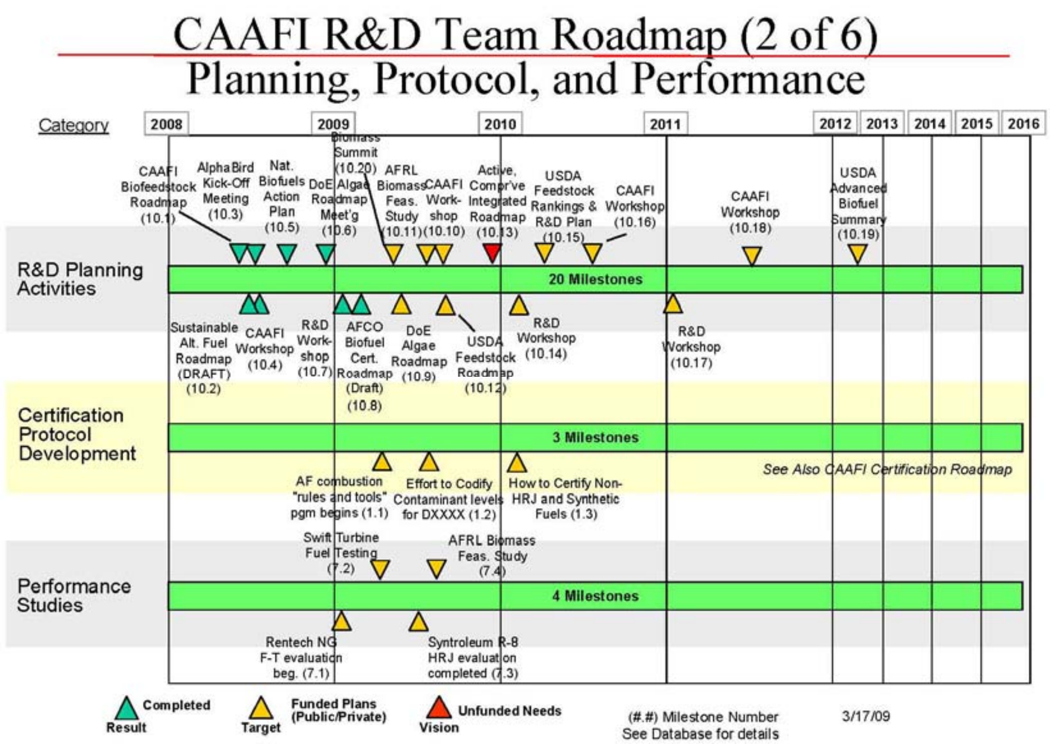



**Figure B-2.**

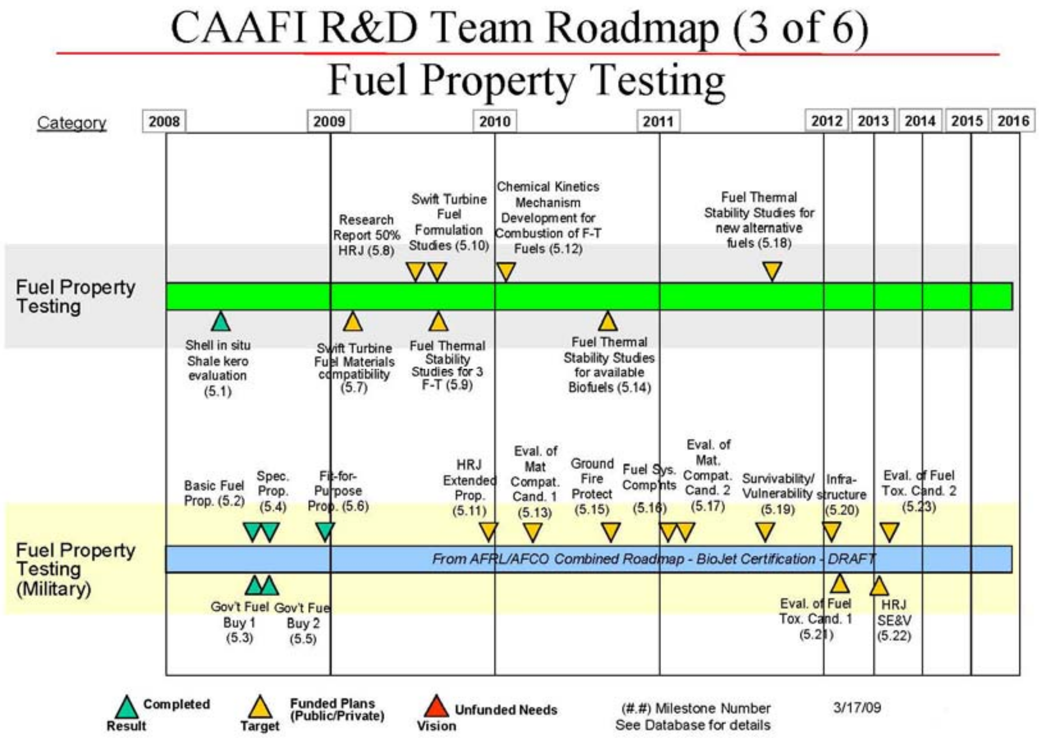



**Figure B-3.**

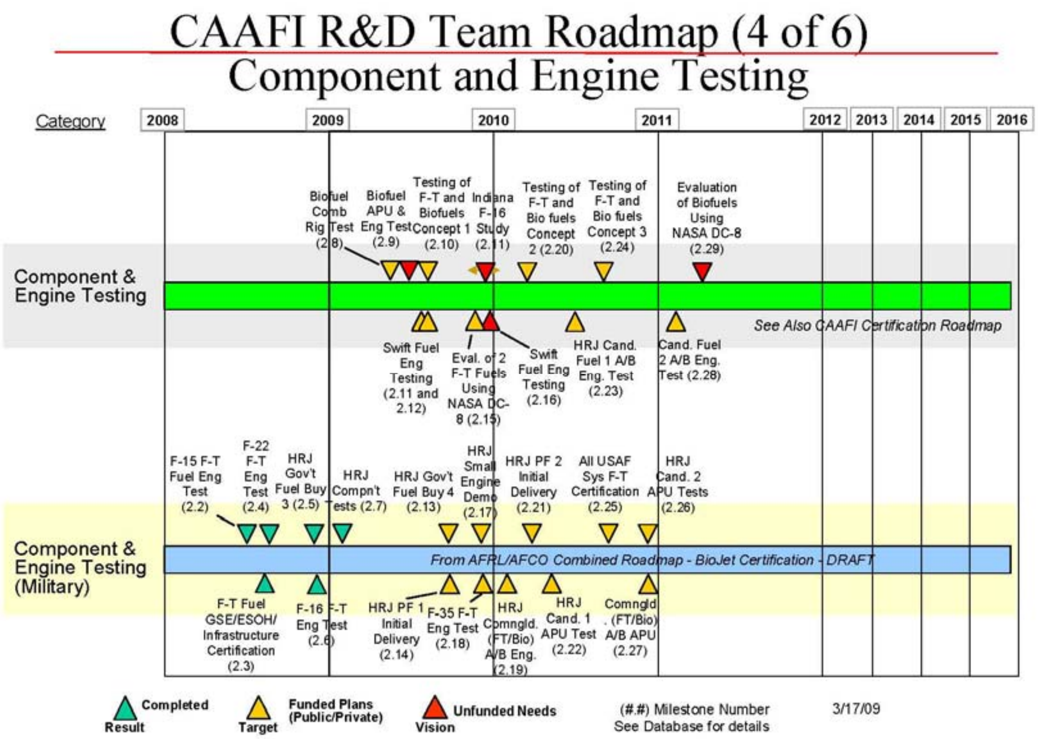



**Figure B-4.**

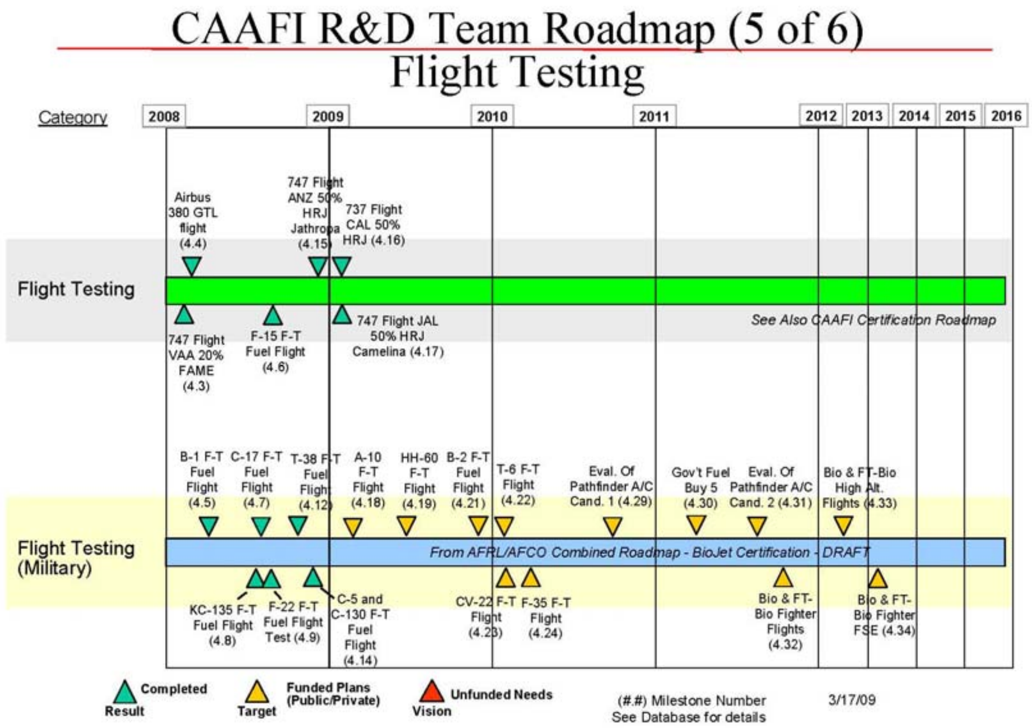



**Figure B-5.**

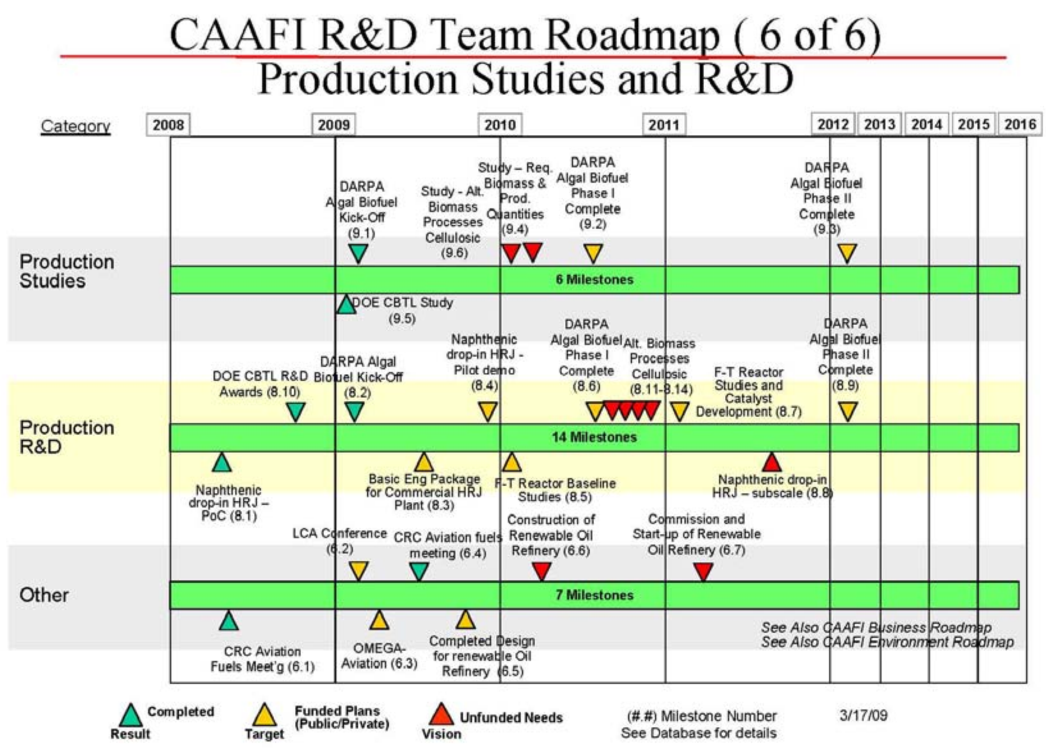



**Figure B-6.**

Supplement to CAAFI R&D Team Roadmap (1 of 6)
Feedstock Roadmap Milestone Description

The following text provides descriptions for each of the milestones listed on the Commercial Aviation Alternative Fuel Initiative (CAAFI) R&D Feedstock Roadmap.

**Swimlane #1: OIL SEED PLANTS.**
**(Plants whose seeds contain oil that is suitable for biofuel)**

Optimized Castor Study (In Work): A modified Castor plant with about 2X the oil yield of present Castor plants has been developed in the lab and will be tested in large scale plots in Brazil (see below). This could provide biofuel for near-term applications.

Camelina Assessment (Unfunded): This feedstock appears promising for present biofuel applications using fallow farmland in North America. A Life Cycle Assessment needs to be performed.

Jatropha Harvesting Prototype (Unfunded): Jatropha appears promising for near-term oil production without competing for farmland or irrigated fresh water. However, the plant's oil seed currently needs to be harvested by hand, and an automated process needs to be developed to reduce production costs and reduce human contact with the poisonous plant.

Optimized Castor Plot (Funded): The resulting modified optimized castor plant (see above) will be planted in a large scale test plot in Brazil to validate productivity.

Oilseed Inventory Study (Unfunded): The USDA is wishing to perform a study that accurately describes the various oil seed crops, their performance, and the rate at which such plants could be scaled up for commercial production.

Large Scale "Regional Solution" Farms Developed (Unfunded): It is anticipated that there will not be one bio-feedstock for world-wide production of biofuel, but there will be multiple solutions, depending on the political-techno and geographic location. Large scale farms are thought to be developed that are suitable for each region of the world.

**Swimlane #2: HALOPHYTES**
**(Salt water tolerant plants that could also yield oil.)**

Euphorbia Analysis (In Work): Research into the plant Euphorbia Tirucalli (commonly known as the petroleum plant) for possible development as a feedstock for biofuels. The plant is undergoing preliminary evaluation for its salt water tolerance and is being grown in desert areas.

Salicornia Analysis (In Work): A life cycle analysis of the Salicornia plant, which produces both food and fuel. Development work is primarily being conducted by Global Seawater Foundation.

Seashore Mallow Analysis (In Work): Seashore mallow could fill a niche as a biofuel feedstock as the plant's architecture and oil yield are similar to soybeans. Perhaps even more appealing, is that the plant thrives in salty soils where nothing else will grow. In fact, the plant can be irrigated with saltwater. Limited research is under way to evaluate this crop for North American applications.

Halophyte Assessment (In Work): An analysis of various halophytes for their potential to produce bio-oils in various parts of the world and the scale up potential. Various research organizations are conducting work on specific varieties, but a coordinated assessment effort is needed to bring all the results together for analysis.

Euphorbia Prototype Plots (Unfunded): Larger scale test plots of various plants to verify the yield per acre under various growing conditions.

Optimized Halophytes (Unfunded): Plants that have undergone high throughput nursery breeding techniques to increase their oil level as well as other desirable growing characteristics.

Modified Halophyte Prototype Plots (Unfunded): Larger scale test plots of the above plants to verify growth rates and oil yield.

Large Scale Halophyte Farms Developed (Unfunded): Commercialization of the above modified Halophyte plants.

GMO Halophyte test plot (Unfunded): Genetically modified versions of the above halophyte plants to specifically further improve its oil yield.

8 Tons Salicornia Oil (Unfunded): Expected bio-oil output of large scale test farms, such as Global Seawater Foundation.

**Swimlane #3: ALGAE**
**(Macro & Micro salt and fresh water organisms having oil content)**

Cyanobacteria Study (In Work): A study to evaluate if cyanobacteria, which are faster growing and hardier than algae, can be genetically modified to produce oil and grown in photobioreactors to economically produce biofuel.

Dewater Study (In Work): Several researcher are evaluating how to economically separate the small amount of algal biomass (typically < 0.1%) contained in the large amount of water (>99.9%) used for growing.

Oil Extraction (In Work): Research into how to break down the algae cell walls and economically extract oil from various algae strains in a production type setting.

Heavy Metal Removal (In Work): Ways to economically remove the heavy metals that can be found in algae grown in waster water and/or with coal flue gas. These metals would poison the fuel processing catalysts used at fuel refineries.

DOE Algae Roadmap (In Work): DOE is developing an algae biofuels roadmap. Draft expected to be completed for intra-government review in Fall 2009.

Algae Strain Study (In Work): Of the 40,000 different algal strains that are believed to exist in the world, research the additional strains (beyond the 3,000 varieties) that were studied in the Aquatic Species Program.

Algae Demo Plants (In Work): Numerous scaled algae demonstration plants are claimed to be in development around the world. Seambiotic, in Israel, is one such prototype plant known to be currently producing algae using flue gas.

Cost of Algae Study (Unfunded): A detailed economic study to assess the economic viability of algae to compete with fossil fuels. It is believe that an integrated production approach, that also utilizes valuable algae co-products, will be required.

Light & $CO_2$ level study (Unfunded): Some previous work has been performed on limited algal strains to assess their growth characteristics under varying light and $CO_2$ levels, but more studies would be required for the optimal algae strains yet to be discovered.

GMO Cyanobacteria Study (Unfunded): A more in-depth study (from above) to evaluate the probability and cost of developing a genetically modified cyanobacteria that has oil producing characteristics.

Results from DARPA project (In Work): The goal of this multi-million dollar program (BAA 08-07) is to develop the technical capability and commercial experience to produce an affordable JP-8 (i.e. military version of commercial Jet-A fuel) surrogate fuel from algae.

USDA algae funding report (Unfunded): A report summarizing the R&D taking place for algae.

New Algae Techs Ready (Unfunded): The assumed breakthrough technologies are developed to address the: optimal algal strains, dewatering, harvesting and oil extraction challenges that remain for this technology to become economically competitive with fossil fuels.

Cyanobacteria Scaled Demo (Unfunded): A scaled demonstration version of the GMO cyanobacteria that was developed (see above.)

GMO Algae (Unfunded): Genetically modified algae organisms are developed that have: much higher oil content, resistance to invading algae species and grazers, higher productivity, high culture stability and auto-bioflocculation tendencies.

Large Scale Algae Plants Developed (Unfunded): After the technical and economic breakthroughs are achieved, it is envisioned that vary large scale algal farms will be developed to start commercial operation of algae oil for biofuel.

Cyanobacteria Plant Developed (Unfunded): If the GMO cyanobacteria can be developed, economically produced and is socially acceptable, it is envisioned that this hardier and higher productivity organism may displace algae as the main oil producing biofeedstock.

**Swimlane #4: CELLULOSE FEEDSTOCKS**

Billion Ton Study (Completed): Report conducted by DOE's Oak Ridge National Lab (ORNL) on "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The

Technical Feasibility of a Billion-Ton Annual Supply." It showed that 1.3B tons/year of biomass could be harvested to meet 1/3 of U.S. fuel needs by 2030.

BCIWG Report (In Work): The Biomass R & D Board Biomass Conversion Interagency Working Group (BCIWG). The Biomass Research and Development Board established an interagency working group to guide the exploration of cost effective commercially viable processes for converting cullulosic and other biomass to biofuels (ethanol, higher alcohols, and green gasoline, diesel, and aviation fuels.) The group is comprised of NSF, DOE, USDA, EPA and DOD and other agencies. The BCIWG is authoring a 10 year Federal RD&D biomass conversion plan report.

Cellulose to biojet flight demo (not funded): A flight demonstration of a biojet fuel made from cellulose via enzymatic deconstruction and synthetic biology buildup of pure hydrocarbon molecules (alkanes.)

Cellulosic Ethanol becomes cost competitive (funded): A (hoped for) milestone where sufficient R&D has overcome the cost hurdles in making commercial ethanol production less expensive when using a cellulosic conversion processes versus the conventional corn starch method.

Cellulose to biojet demo plant via pyrolysis (not funded): A small demonstration plant that more efficiently converts cellulosic material into a bio-crude oil that can then be fed into conventional oil refineries for processing.

Cellulose/Sugar/Algae Prototype Demo (not funded): Sugars that are derived from hemicellulose from woody plants can be used as nutrients to rapidly grow algae in non-sunlight reactors (i.e. heterotrophic conditions.) Heterotrophic growth of algae on pentose sugars from hemicellulose may be a promising approach for algae production as it would not compete with either food sugar or ethanol sugars, which are all hexose sugars.

Large scale cellulose farms (not funded): Initial commercialization of prairie grasslands that are (no till) seeded with switchgrass and harvested with no environmental damage.

GMO plants for easy sugar conversion (in work): Genetically modified plants, such as poplar trees, that have enhanced growth characteristics such that processing enzymes may more easily break down the lignin for conversion into sugars

**Swimlane #5: OTHER FEEDSTOCKS**
**(All other plants not covered above.)**

DOE's CBTL study done (In Work): A Coal & Biomass To Liquid (CBTL) study where biomass is used to offset $CO_2$ emissions that would normally be environmentally prohibitive in a conventional Coal To Liquid (CTL) fuel production plant.

Revise EISA to include biomass credit (In Work): The present Energy Independence Security Act (EISA) presently does give environmental credit for using some types of biofeedstocks in certain fuel processing methodologies (e.g. bio-oil used in an oil refinery to make a biofuel/fossil fuel mixture.)

Overall Feedstock Assessment (Unfunded): A study to evaluate all other known types of bio-feedstocks (e.g. switchgrass to alkane hydrocarbons through synthetic biology) that could be used to produce biofuel for aviation.

Various Scaled Test Plots (Unfunded): The growing of emerging bio-feedstocks (see above) that could be used for biojet fuel.

Terra Preta Test Plot for CBTL (Unfunded): A scaled agricultural project where the excess solid carbon from the CBTL process is buried in farm plots to evaluate the effect on crop production.

DOE's CBTL & Algae Demos Done (Unfunded): A NETL demonstration project with APS (Arizona Public Supply) where coal is gasified for power generation and algae are grown with flue gas effluent to capture and utilize the $CO_2$.

Large Scale Cellulose Farms for synthetic biofuel & CBTL (Unfunded): After the fuel processing technologies are developed that can economically convert cellulose into biofuels, it is envisioned that large scale (prairie?) farms will be developed to grow cellulose (e.g. switchgrass, etc.)

**Swimlane #5: OTHER**
**(Primarily activities to coordinate with)**

CAAFI biofeedstock roadmap (Done): This roadmap which was developed on January 27th in Dayton, Ohio by 80 representatives from the aviation, biofuel and feedstock industries.

USDA Feedstock Roadmap (Unknown): It is thought that the USDA should develop its own feedstock R&D roadmap, which would include recommendations from this feedstock roadmap.

USDA Feedstock Rankings and R&D Plan (Unknown): Once the roadmap is developed, funding should be secured for future projects that are underfunded or unfunded, based on their ranked importance to provide biofuel feedstocks for aviation as well as ground transportation. The R&D plan will lay out a formula to achieve US energy independence with help from carbon neutral biofuels.

USDA Advanced Biofuel Summary (Unfunded): A final summary report published by the USDA reviewing all of the next generation feedstocks that could be used for making biofuel and making recommendations.

## Appendix B Reference

Congressional Testimony – House Science and Technology Committee, Subcommittee on Space and Aeronautics, on Aviation and Emerging Use of Biofuels, Dr. Lourdes Maurice, Chief Scientific and Technical Advisor, Federal Aviation Agency, Appendix A, March 25, 2009

## APPENDIX C

## Carbon Capture

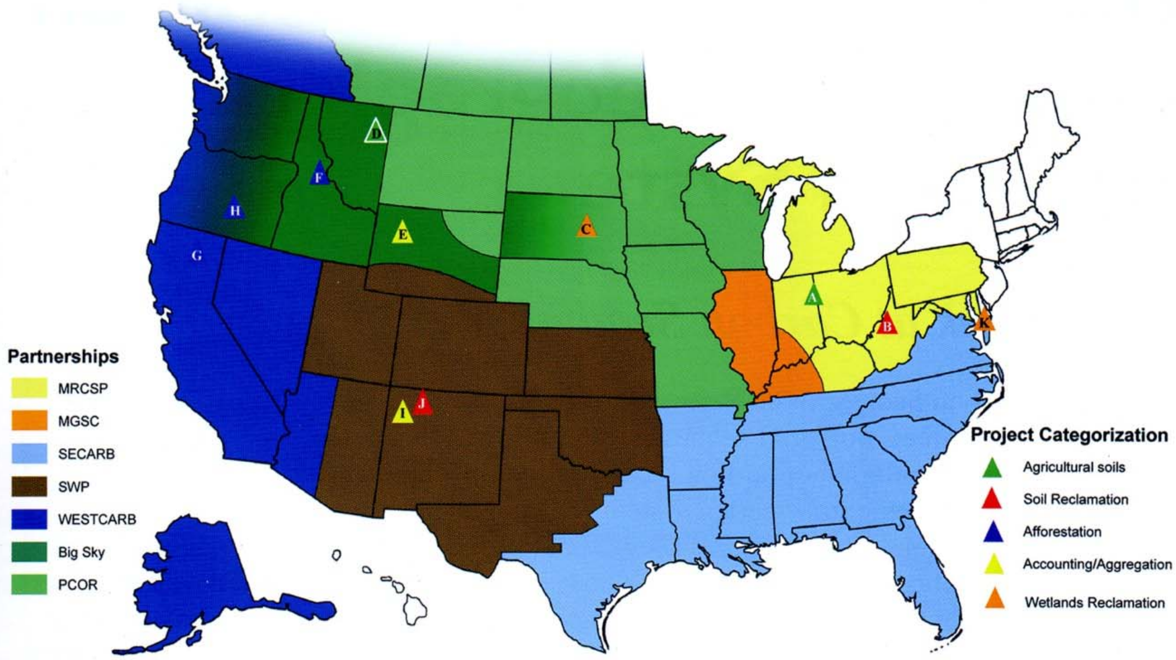
The generation and control of carbon dioxide has become a societal concern and a major constraint in the use of fossil fuel. This appendix provides additional information on the structure that has been organized to document the problem and define the solution elements.

The **Carbon Sequestration Atlas of the United States and Canada** was prepared under the direction of the DOE National Energy Technology Laboratory (NETL), released in March 2007 and has become a prominent carbon control source document. Some of the material below is representative of that document and can be examined in greater detail by direct reference to that 86 page publication. A web site www.natcarb.org contains an interactive digital map that allows the evaluation of sources and potential sinks at national, regional, and local levels. The *DOE Carbon Sequestration Technology Roadmap and Program Plan*, 2007 [1] and the *Clean Coal Technology Roadmap / Coal Utilazation Research Council, Electric Power Research Institute, Department of Energy Consensus Roadmap* [2] also provide relevant data, objectives, and statistics.

Seven Regional Carbon Sequestration Partnerships (RCSPs) have been formed to define, test, and demonstrate technologies and regulations appropriate for the different regions of the U.S. and Canada. Figure C-1 shows these regions and the Validation Phase Test Sites. Field projects have demonstrated the ability to "map" injected $CO_2$ at a much greater resolution than anticipated and for perfluorocarbon tracers (PFTs) [Brookhaven Nat'l Lab, Close-coupled subsurface Barrier Technology] to track $CO_2$ throughout a reservoir. A large amount of data has been assembled estimating sequestration capacities and its correlation with large $CO_2$ point sources. Results to date have identified enough sites to accommodate current rates for hundreds of years. [1 (31)] These seven RCSPs encompass the locations of 97 % of coal-fired emissions, 97% of industrial emissions, 96% of the total landmass and essentially all of the potential sequestration sites in the U.S. [1 (31)]

## Regional Carbon Sequestration Partnerships

***Validation Phase Terrestrial Field Tests***




| Partnership | Project Location | Land Categorization | Project Summary | Estimated $CO_2$ Capacity |
|---|---|---|---|---|
| A MRCSP | Region-wide | **Agricultural** | Demonstrating carbon sequestration on existing farm lands. Determine rate of sequestration and potential for different tillage practices to increase storage. | 250 Mt over 20 years |
| B MRCSP | Region-wide | **Mineland** | Demonstrating carbon sequestration in reclaimed mine soils. Determine reclamation and land management practices that increase storage. | 100 Mt over 20 years |
| C PCOR | Great Plains wetlands complex (PPR) | **Wetlands** | Sequestration demonstration in wetlands/grasslands that will provide carbon offsets, develop protocols and standards, and provide a market-based carbon sequestration strategy. | 14.4 Mt |
| D Big Sky | North Central MT | **Agricultural** | Objectives are to (1) quantify and determine cropland management practices that optimize carbon sequestration and (2) develop MMV protocols to evaluate carbon sequestration for enrolled farms. | 60 Mt over 20 years |
| E Big Sky | Eastern WY | **Rangeland** | To determine the sequestration effects of (1) grazing intensity and seasonality of grazing on native northern mixed grass prairie and (2) improvement practices on degraded northern mixed-grass prairie. | 30 Mt over 10 years |
| F Big Sky | Region-wide | **Forest** | Identify strategies for maintaining or increasing sequestration in forests through understanding the effects of forest management on different carbon pools in forests. | 640-1,040 Mt over 80 years |
| G WESTCARB | Shasta County, CA | **Forest and Rangelands** | Validation of forest growth potential for rangelands; Change in forest management; Fuels management to reduce risk of uncharacteristically severe wildfire and prevent emissions | 4,600 Mt over 80 years (CA) |
| H WESTCARB | Lake County, OR | **Forest and Rangelands** | Afforestation using fast-growing tree species Fuels management to reduce risk of uncharacteristically severe wildfire and prevent emissions | 900 Mt over 80 years (OR) |
| I SWP | Region-wide | **Multiple** | Develop a carbon reporting and monitoring system that functions consistently across hierarchical scales and is compatible with the existing technology underlying the 1605b reporting system. Project will develop improved technologies and systems for direct measurement. | TBD |
| J SWP | San Juan Basin Coal Fairway (Navajo City, NM) | **Rangeland/ Riparian** | Desalinate produced water from the ECBM pilot and use the water for irrigating a riparian restoration project. Reintroducing woody plant species along riparian areas and reestablishing native grasses and shrubs in upland areas. Project represents a combined ECBM-terrestrial sequestration project. | TBD |
| K MRCSP | Cambridge, MD | **Wetlands** | Develop estimates of carbon sequestration rates in marshes over time. Understand influences of carbon management practices on sequestration rates. Develop sampling protocol for sequestration validation. | TBD |

**Figure C-1. Regional Carbon Sequestration Partnerships**

The following map shows the major North American $CO_2$ sources. Note that “blue” designates electricity generation; “red” petroleum and natural gas processing; “orange” cement plants; “yellow” ethanol; “purple’ refining and chemical; “green” agricultural processing; and “black” unclassified.

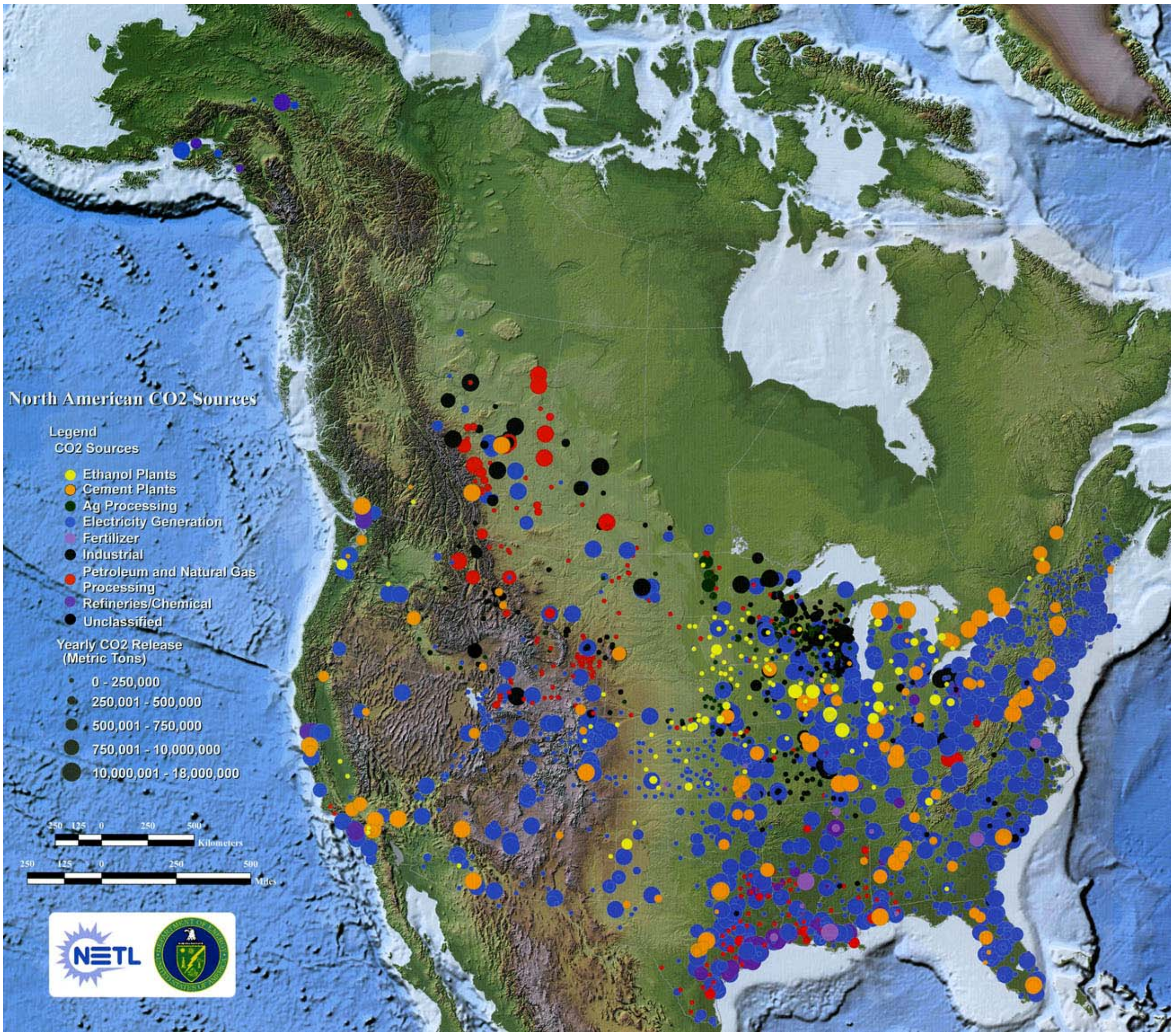
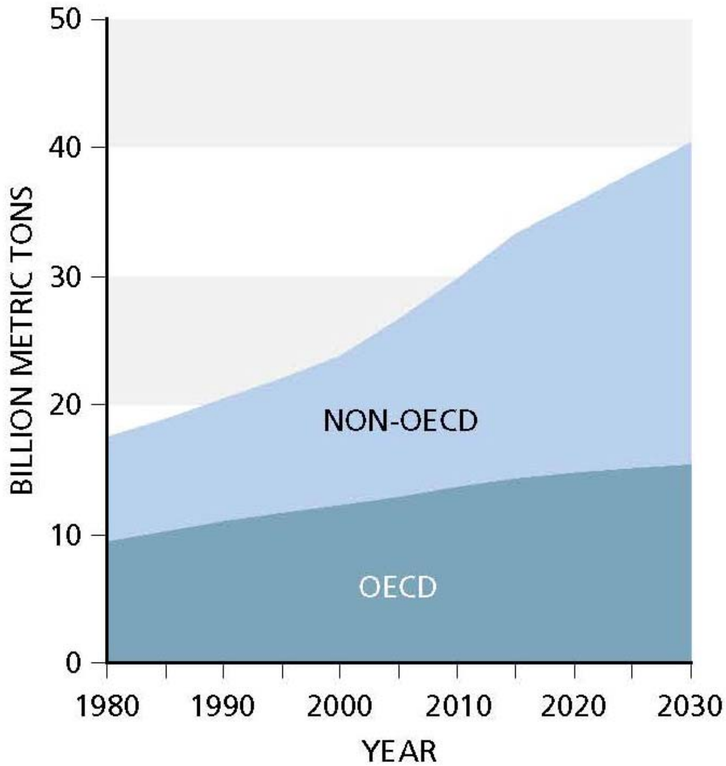



**Figure C-2. Emissions Source Map**

While the U.S. share of global emissions will decline as energy use in the developing world continues to grow rapidly over the next few decades, the EIA projects that the amount of U.S. emissions could rise by about one-third by 2030 with the emissions from transportation maintaining roughly one-third of this larger number. [3]

Figure C-3 below, highlights the projected $CO_2$ emissions impact resulting from the expected dramatic energy use growth in developing countries.




Source: IEA, *World Energy Outlook 2006,* Reference Case.

**Figure C-3. World Carbon Dioxide Emissions**

**International Implications**

Although global warming may still be open to debate, $CO_2$ concentration is not. The atmospheric $CO_2$ levels have increased from 354 ppm in 1990 to 386 ppm today [4] and it has been estimated that they could double and reach dangerous levels by the end of this century. Drastic curtailment measures are being called for and are achieving popular support, even in the U.S. Significant international rebuke has been directed at the U.S. for failure to participate in the 1997 Kyoto Protocol which aimed to reduce GHG emissions to 5.2% below the 1990 level (29% below the predicted 2010 levels). [5] The protocol would have assigned a 7% reduction to the U.S. GHG emissions by the U.S. in fact increased by 20% over the period from 1992-2007. The conference to define the next set of co-operative actions is scheduled for Copenhagen in December 2009. Some form of carbon control is judged to be inevitable. This would put huge pressure on the use of fossil fuel, raising any coal related plant construction costs and production costs.

An important issue is inclusiveness. Countries that adopt aggressive carbon control measures and the attendant additional costs and inefficiencies, would be at a significant competitive disadvantage in dealing with any country that didn't adopt and operate by the same standards. A

deficiency of the Kyoto Protocol was that China and India were not included and continue to be major emitters. China now uses more coal than the U.S., Europe, and Japan combined, thus making it the world's largest emitter of gases. [6] A May 2009 press release reported that China's 2010 budget has removed or reduced carbon capture provisions in favor of dealing with economic challenges. The Science and Public Policy Institute, a Washington D.C based organization skeptical of GHG theories, published a document in March 2009 which makes the point "If the entire Western world were to close down its economies completely and revert to the Stone Age, without even the ability to light fires, the *growth* in emissions from China and India would replace our *entire* emissions in little more than a decade." [7]

Insight into the results from preliminary multination discussions at conference in Bonn, Germany in early June 2009 was revealed in a rare news release. The U.S. has made it clear that China must be part of a new climate package, and without China there's no deal. But the chief U.S. climate envoy stated that the U.S. was not demanding that China accept mandatory emissions targets. "We don't expect China to take a notional cap at this stage." China has asked the U.S. to deliver top of the line technology as part of a new agreement. China, India, and other developing countries say "targets would constrain their economic growth, and their first priority is to fight poverty." [8]

**U.S. Implementation**

The Archer Daniels Midland company has started $CO_2$ injection from their Decatur, Illinois ethanol plant into Mount Simon Sandstone more than a mile deep. Between 2010 and 2013, they expect to inject and initiate long term monitoring of up to a million tons. [9] While this is a constructive and commendable action by a private industry, note that the quantity is below the demonstrated Sleipner (one million tons per year) and Weyburn (two million tons per year) levels and well below the levels expected from either coal-fired power generating or CTL plants. In other words, risks and immature processes are motivating caution.

The Midwest Regional Carbon Sequestration Partnership has completed a preliminary geologic characterization and sequestration test at First Energy's R.E. Burger Plant near Shadyside, Ohio. This area is in the Appalachian Basin (near site 8 on the Validation Table) and is geologically complex. Results of the evaluation indicated porosity, void space, and permeability of the target Oriskany and Clinton Sandstones formations at depths between 5,500 and 8,000 feet were lower than expected. Pressure in the formations rose unexpectedly with very low injection rates. This demonstrates the complexity and nonuniformity of sequestration and the need for extensive testing and formulation to identify appropriate storage sites.[10]

Duke Energy, the nation's largest coal-based electricity producer, is currently constructing in Edwardsport, Illinois the first commercial scale IGCC plant in the U.S. The original design, consistent with MIT "advise," contained the most advanced and efficient generation technology, but did not include carbon capture. Duke was given a $1 million grant and after study is considering an 18% capture when the plant goes on-line in 2012. Their position is that significant additional time and study are required to move to a higher capture level. This is indicative of the complexity, cost, and risk perceived in this process which is yet to be demonstrated at scale.

**Right and Liabilities**

The legal rights in the pour space have been determined not to be the traditional subsurface rights and at this point are very much in doubt. Some experts believe that deep sequestration rights may vest with the surface owner and for EOR with the oil lessee. Eminent domain issues are quite probable and the determinations will almost certainly vary by state. The question is, if after a hundred years, sequestered carbon escapes or contaminates a water supply, who is responsible and liable? The Legislatures in Texas and Illinois, in order to clear the way for proposed projects, have established state liability for the long term injected $CO_2$. [1 (15)] In any case, because banks do not like long term undefined and immeasurable risk , this issue continues to be an impediment to financing.

**Capture Cost**

The cost of capture is typically several times greater than the cost of transport and storage. Capturing carbon from flue gas in a current powdered coal-fired electricity generating plant is very difficult and the renovations that would be necessary have been estimated to increase the electricity cost by as much as 60-100%.

Use of gasification, instead of direct combustion, in a Integrated Gasification Combined Cycle (IGCC) configuration provides a significant advantage in that the carbon dioxide is produced in a relatively clean concentrated and pressurized stream ready for capture and transportation. Figure C-4 below demonstrates this advantage. It shows the cost of adding carbon capture to a IGCC design has been estimated to add approximately 35% to the construction cost and 32% to the electricity cost. The same containment costs for a powered-coal (PC) plant would be 87% and 83%. For a natural gas combined cycle (NGCC) generation plant, the cost increases would be 110% and 43%. The rub is that a traditional 500 MW generating plant can be built for $400,000 and the IGCC replacement for $2.5 Billion. There are approximately 900 old style plants that need to be replaced.

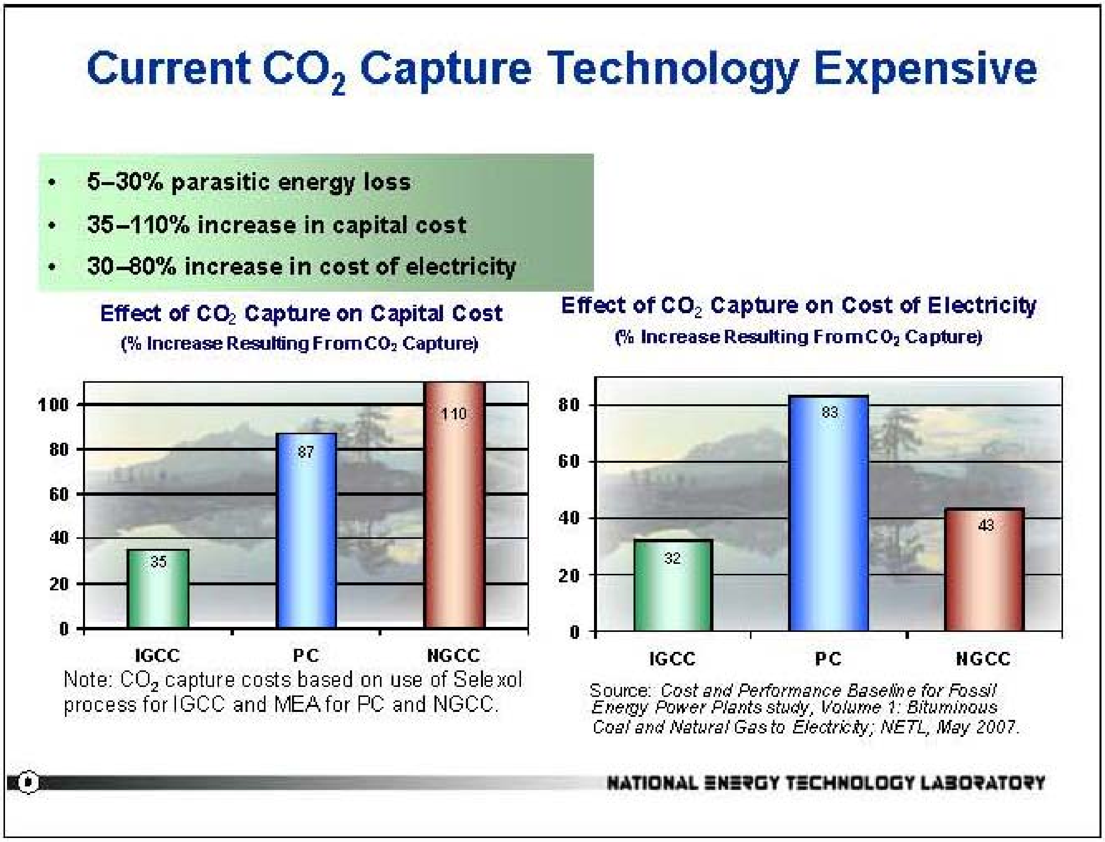



**Figure C-4. Current $CO_2$ Capture Technology**

NETL estimates that sequestration for a CTL plant will add $.07 per gallon ($2.94 per barrel) [11] The RAND report, *Producing Liquid Fuels from Coal: Prospects and Policy* Issues, 2008 [12 (33)] estimates a 5% increase in capital cost and a product cost increase of $5 per barrel.

**Appendix C References**

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10. Coal News and Trends, June 2009
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12. RAND, James T. Bartis, Producing Liquid Fuels From Coal: Prospects and Policy Issues, 2008

# APPENDIX D

## Status of Synthetic Fuel Projects

## 1 July 2009

### Table D-1. Status of Synthetic Fuel Projects

| | | | | Capacity | Primary | Operational | | |
|---|---|---|---|---|---|---|---|---|
| **N** | **Plant** | **Category** | **Location** | **barrels/day** | **Product** | **Date** | **Est.cost** | **Comments** |
| 1 | Nazi Germany (9 plants) | CTL | Germany | 11,500 | a/c fuel, diesel | | | 4.2 Mbbl in1944 |
| 2 | (12 plants) | DCL | Germany | 23,000,000 | gasoline, diesel | | | 23 Mbbl in 1944 |
| 3 | Sasol- Sasolburg | CTL /GTL | South Africa | | | 1,955 | | 1-1980, 2-1982 |
| 4 | Sasol-Secunda ( 2 plants) | GTL | South Africa | 150,000 | a/c fuel, diesel | 1-1980,2-1982 | | Initially CTL converted to GTL-2004 |
| 5 | PetroSA-MosselBay | GTL | South Africa | 36,000 | | 1992 | | 1st GTL plant; dev'd new FT catalysas |
| 6 | Shell-Bintutu | GTL | Malaysia | 14,000 | | 1993 | | |
| 7 | Sasol-Oryx | GTL | RasLafffan,Qatar | 34,000 | diesel,gasoline | 2006 | | Catalyst Problems-1st diesel Jul '07 |
| 9 | Wits COMPS-Golden Nest | CTL | Baoji,Shaanxi China | | diesel,gasoline | 2008 | | On-line 12/08;short run; No data |
| 10 | Shenhua Erdos-Headwaters | DCL | Majiata, I. Mongolia | 24,000 | diesel | 2008 | 1.5B | 1st "modern" DCL pt; 303 hr run-failure |
| 11 | Laun Group-Westhawk | CTL | Shanxi China | 3,200 | | 2008 | | |
| 12 | Yayai Group | CTL | I. Mongo;ia | 3,200 | | 2009 | | Fire April 09-closed for several months |
| | | | | | | | | |
| 13 | Shell-Pearl | GTL | Ras Laffan, Qatar | 140,000 | | 2011 | | under const |
| 14 | Linc Eneergy- S. Australia | UCG/GTL | Arckaringa Basin | 20,000 | diesel | 2011 | | Planning Phase |
| 15 | Chevron-Escravos | GTL | Nigeria | 34-100,000 | | 2012 | 5.9B | |
| 16 | Sasol Secunda Expansion | GTL | South Africa | inc to 180000 | | 2,015 | | 75% of increase GTL |
| 17 | Sasol-Ningxia | CTL | Ningxia, China | 80,000 | | | 5-7 B | Feasibility Phase II - due late 2009 |
| 18 | Sasol-Shenhua Group | CTL | Shaanxi China | 80,000 | | | 5-7 B | On hold - identicial to Ningxia |
| 19 | Sasol Limpopo -Mafutha | CTL | South Africa | 80,000 | a/c fuel,diesel | | | Green field -new town |
| | | | | | | | | |
| 20 | Rentech Prod Demo Unit | GTL | Colorado | 10 | a/c fuel, diesel | 2008 | 25M | 2008 - 800 hr run |
| 21 | Syntroleum/ Tyson Foods | BTL | Louisiana | 4,892 | diesel | 2010 | 150 M | Under construction |
| 22 | Mingo County-TGDS-Rentech | MTG/CTL | Mingo Cty,WV | 3-30,000 | | ~2012 | | Starting permits & AIM funding |
| 23 | Rentech-Natchez | CTL | Natchez,Ms | 6-Jul | diesel | | 6.4B | Est. Construction Start late 2010 |
| 24 | Baard Energy | CTL | Wellesville,Oh | 53,000 | a/c fuel,diesel | const. pending | 5B | Last permit(3 Ohio & 1 Fed) 20 Nov 08 |
| 25 | WMPI's Gillberton, Pa | CTL | Pennsylvania | 5,000 | diesel | suspended | 1B | |
| 26 | SES-Consol | MTG | Benwood,WV | 24,000 | gasoline | suspended | 800M | SES withdrew Oct 08 |
| 27 | DKRW's Medicine Bow, Wyo | MTG | Wyoming | 20,000 | gasoline | 2013 | 2.7B | |
| 28 | N. American Coal/Heawaters | DCL | NorthDakota | 30,000 | gasoline | 2013 | 4B | |
| 29 | Eielson AFB | CTL/GTL | Fairbanks, AL | 20/40,000 | a/c fuel, diesel | | 4.1/7.4B | 1st FEED Study- Nov 08; 2nd pending |
| 30 | Crow Nation-Many Stars | CTL | Montana | 50,000 | a/c fuel, diesel | 2016 | 7B | |

# APPENDIX E

## Carbon Tax Cost Effects

A study, *The Future of Electricity*, conducted by the School of Public and Environmental Affairs at Indiana University in May 2009, examined the effect a carbon tax would have on the various methods of electricity generation. Although based on electricity, the comparison is a useful analogy for the impact a carbon tax would have on synthetic fuel production. Particularly for the cases that share a gasification process that is common.

The data also provides an interesting comparison of traditional and emerging renewable energy source costs.

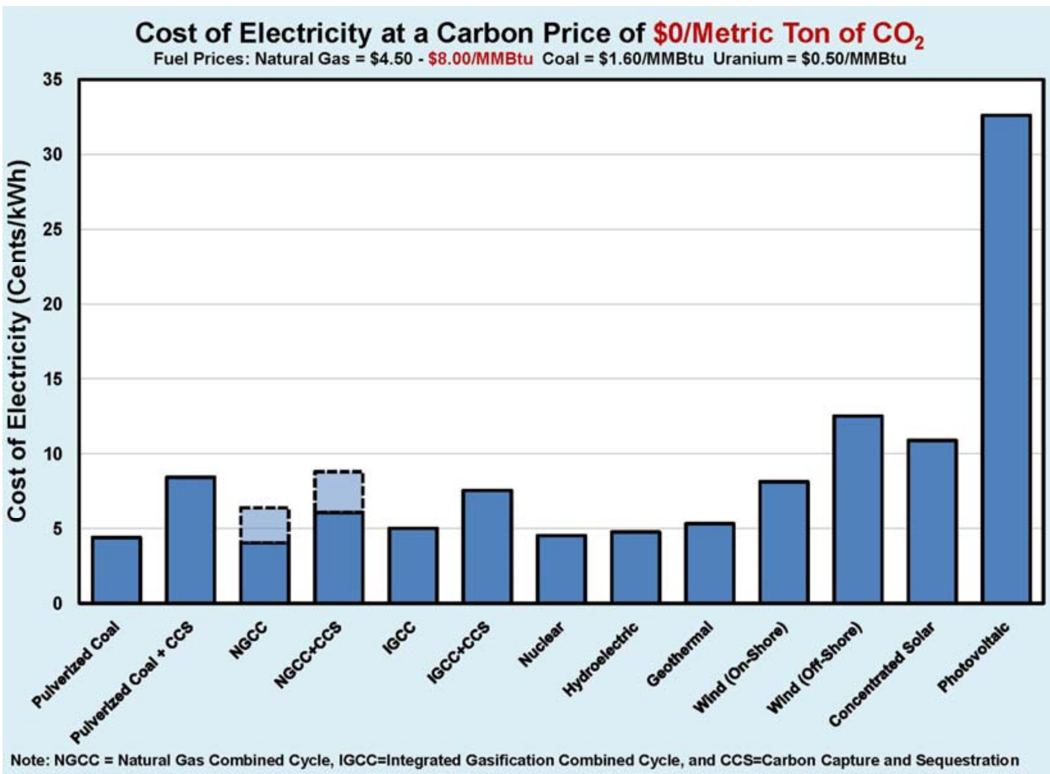


**Figure E-1.**

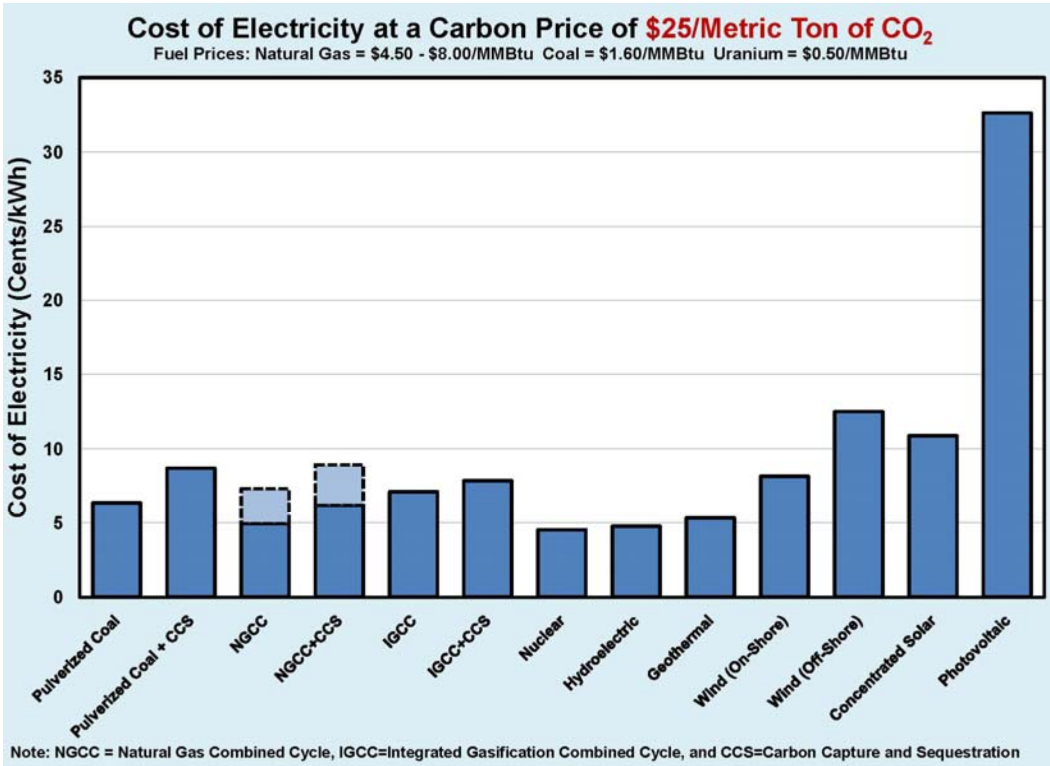


**Figure E-2.**

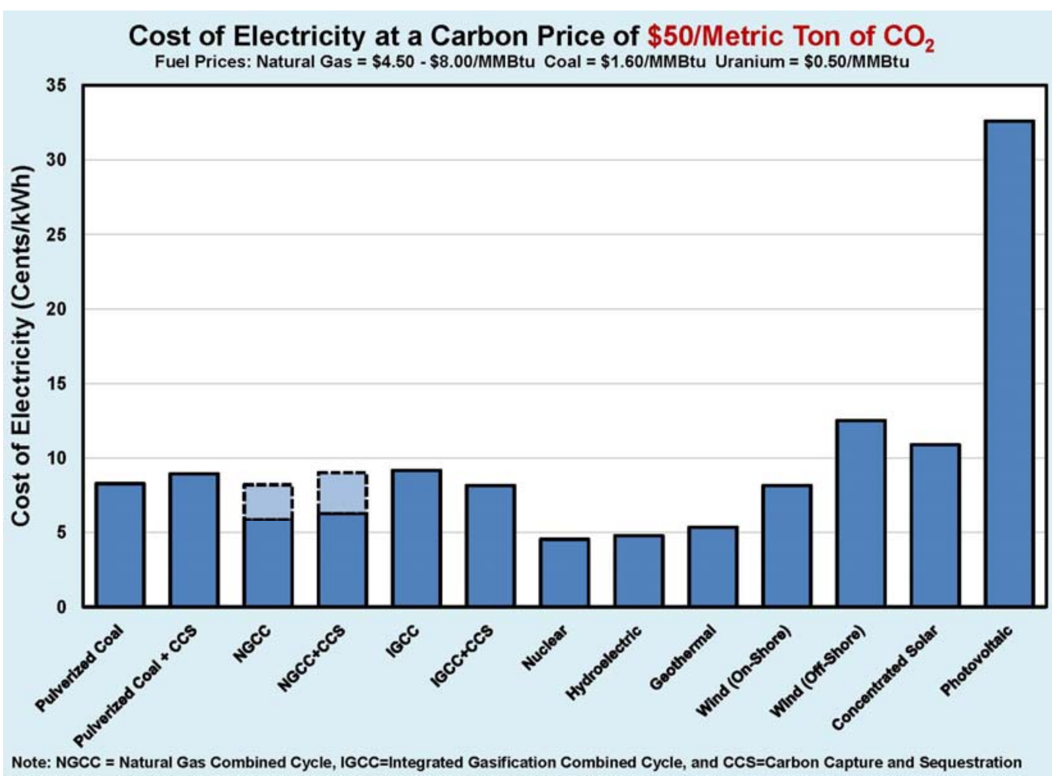


**Figure E-3.**

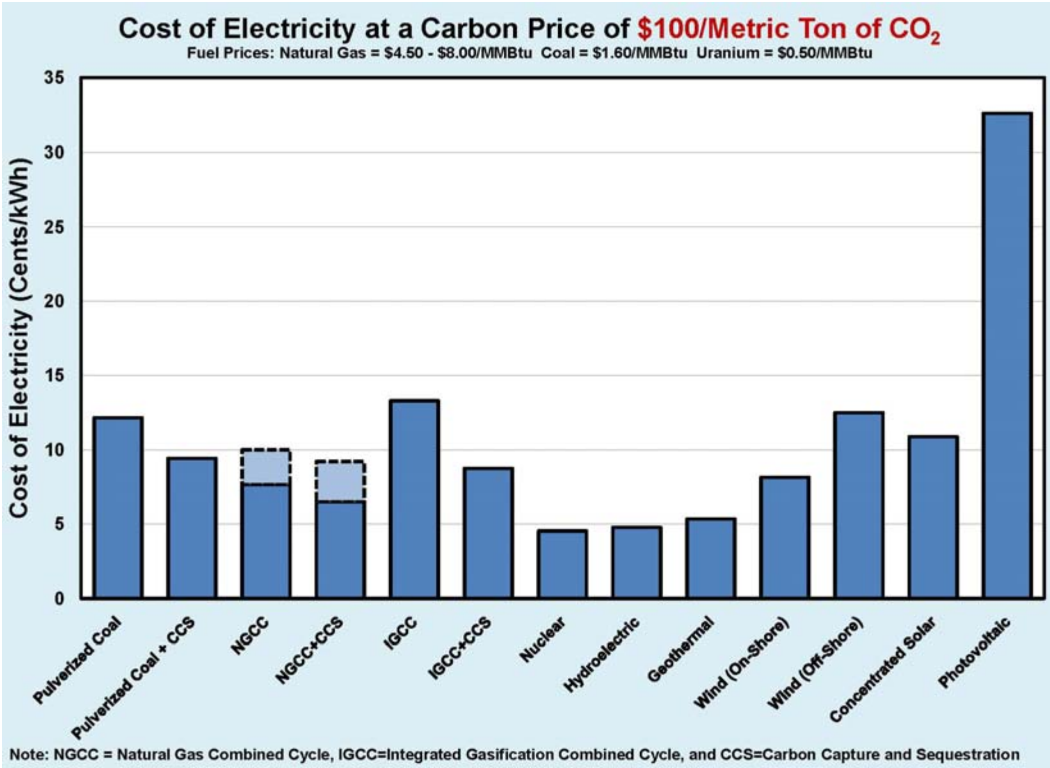


**Figure E-4.**

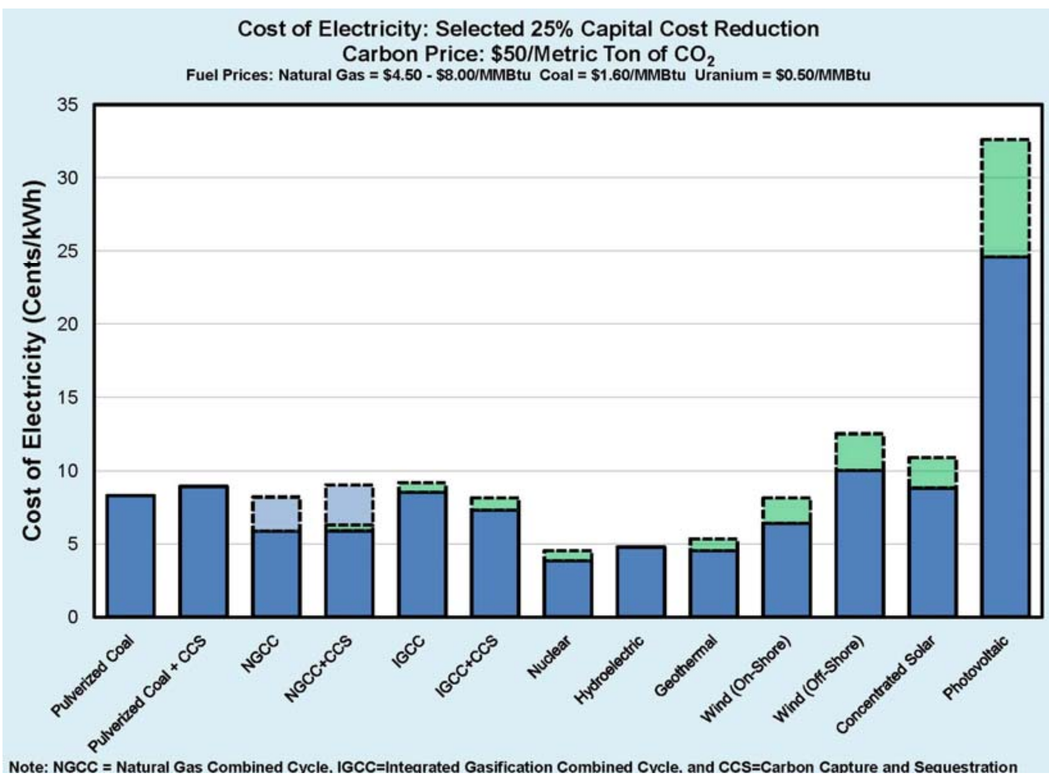


**Figure E-5.**

## LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

| | |
|---|---|
| AFCO | Alternative Fuel Certification Office |
| Algal | Pertaining to or caused by Algae |
| ARPA-E | Advanced Research Projects Agency – Energy |
| BBOE | Billion Barrels Oil Equivalent |
| BTU | British Thermal Units |
| BTL | Bio-to-Liquid |
| CAAFI | Commercial Aviation Alternative Fuel Initiative |
| CBTL | Coal and Biomass to Liquid Fuel |
| CCS | Carbon Capture and Storage; Carbon Capture and Sequestration |
| CERA | Cambridge Energy Research Associates |
| CFCs | chlorofluorocarbons |
| CNCEC | China National Chemical Engineering Corporation |
| $CO_2$ | Carbon Dioxide |
| COMPETES | Creating Opportunities to Meaningfully Promote Excellence in Technology, Education and Science |
| COMPS | Centre of Material and Process Synthesis |
| CONUS | Continental United States |
| CTL | Coal-to-Liquid Fuel |
| DCL | Direct Coal Liquefaction |
| DKRW | DKRW Energy LLC |
| DOD | Department of Defense |
| DOE | Department of Energy |
| DTL | Direct-to-Liquid |
| ECP | Engineering, Construction, Procurement |
| EIA | Energy Information Administration |
| EISA 2007 | Energy Independence and Security Act of 2007 |
| EOR | Enhanced Oil Recovery |
| EPA | Environmental Protection Agency |
| FEED | Front-End Engineering Design |

| | |
|---|---|
| FOB | Free On Board; cost at a particular location determines shipping cost responsibility |
| F-T | Fischer-Tropsch |
| FTS | Fischer-Tropsch Synthesis |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gas |
| GSI | General Synfuels International |
| GTL | Gas-to-Liquid Fuel |
| HCFCs | hydrochlorofluorocarbons |
| HRJ | Hydro-Treated Renewable Jet |
| ICAO | International Civil Aviation Organization |
| ICP | In situ Conversion Process |
| IEA | International Energy Agency |
| IGCC | Integrated Gasification Combined Cycle |
| IHS, Inc. | International Information and Analysis – HIS Jane's,<br>HIS CERA, HIS Global Insight, HIS Herold |
| IPCC | Intergovernmental Panel on Climate Control |
| JGC Corp | Japanese energy related engineering and development company |
| KBR, Inc. | Formerly known as Kellogg, Brown, and Root, a subsidiary of Halliburton |
| LCA | Life Cycle Assessment |
| LHV | Low Heat Value |
| LNG | Liquefied Natural Gas |
| LPG | Liquefied Petroleum Gas |
| MPG | Multi Purpose Gasification |
| MSW | Municipal Solid Waste |
| MTG | Methanol to Gasoline |
| MTL | Methanol-to-Liquid Fuel |
| NATIBO | North American Technology and Industrial Base Organization |
| NETL | National Energy Technology Laboratory of DOE |
| $NO_X$ | Nitrogen Oxide |
| NREL | National Renewable Energy Laboratory of DOE |

| | |
|---|---|
| PDU | Product Demonstration Unit |
| PEM | Plasma-Enhanced Melter |
| PPM | Parts Per Million |
| RAND | RAND Corporation – nonprofit research and analysis organization – first "think tank" |
| RFI | Request for Information |
| RFS | Renewable Fuel Standards |
| SBCR | Slurry Bubble Column Reactors |
| SECAF | Small and Emerging Contractors Advisory Forum |
| SES | Synthesis Energy Systems |
| $SO_X$ | Sulfur Oxide |
| Syngas | Synthetic Gas |
| TGDS | Transgas Development Systems LLC |
| Tosco | Contraction of The Oil Shale Company – merged with Phillip Petroleum in 2001 |
| TW | Trillion Watts |
| UCG | Underground Coal Gasification |
| UK | United Kingdom |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USA | United States of America |
| USAF | United States Air Force |
| USDA | U.S. Department of Agriculture |
| UTA | University of Texas at Arlington/Austin |
| WTE | Waste-to-Energy |
| WTI | West Texas Intermediate Crude |
| WTW | Well-to-Wheels – Life Cycle Assessment term associated with Greehouse Gas sources |